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alternate space shuttle concepts study

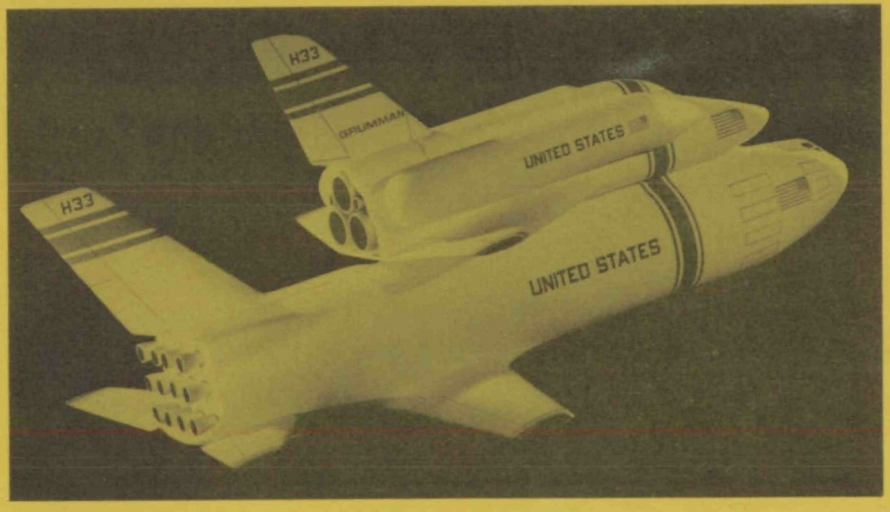
MSC – 03811

FINAL REPORT

(E-1)

Part III Engineering and Development Plan

Volume II ORBITER VEHICLE



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(NASA-CR-146213) AITERNATE SPACE SHUTTLE CONCEPTS STUDY. PART 3: ENGINEERING AND DEVELOPMENT PLAN. VOLUME 2: ORBITER VEHICLE (Grumman Aerospace Corp.) 605 p

N76-71559

Unclas
00/98 17937

CONTRACT: NAS 9-11160
DRL: M010
LINE ITEM: 12

B35-43RP-13
6 JULY 1971

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NORTHROP

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FINAL REPORT
(E-1)

Part III
Engineering and Development Plan

Volume II
ORBITER VEHICLE

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FOREWORD

This document is one of a series prepared in accordance with Contract NAS 9-11160, Study of Alternate Space Shuttle Concepts. Listed below are the final documents required by Data Line Items Nos. 11 through 15 of the contract. Those listed under B & P Documents were developed under the Grumman/Boeing Bid and Proposal effort in anticipation of proposals for a Space Shuttle System industry competition. The letter to the right of each document title is a unique volume identifier which appears in the upper right hand corner of the corresponding document cover.

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Executive Summary	
Technical Summary	
Volume I Shuttle Definition	A
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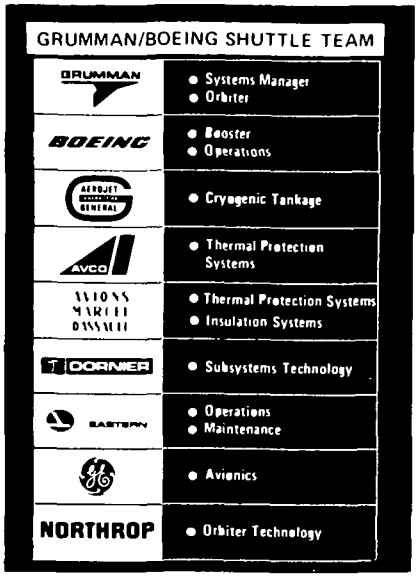
INTRODUCTION

ALTERNATE SPACE SHUTTLE CONCEPT STUDY

The study of Alternate Space Shuttle Concepts (ASSC) was initiated on July 6, 1970, in parallel with studies of the fully reusable two-stage-to-orbit earth orbital shuttle

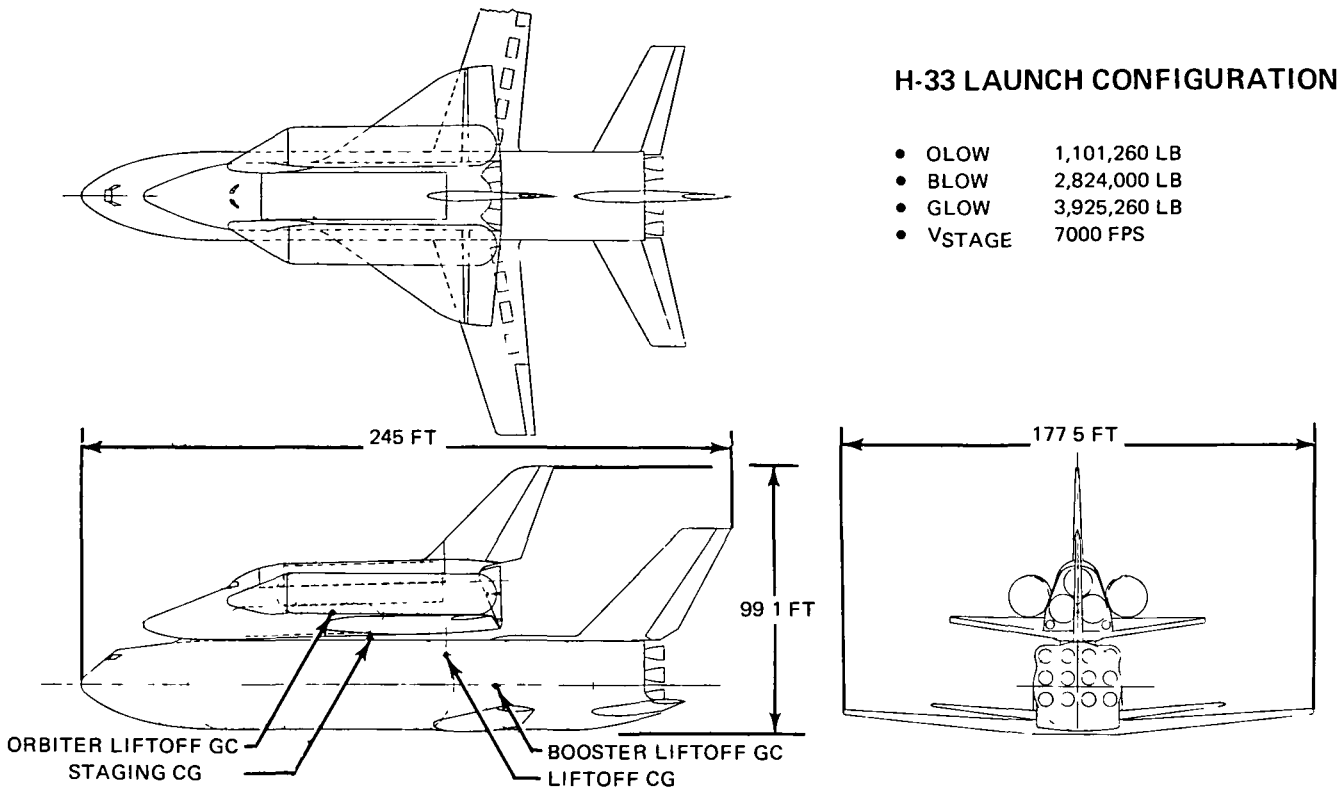
The ASSC study was conducted jointly by the Grumman Aerospace Corporation, the Boeing Company, and their associates To assure consistency of results, Grumman and Boeing worked closely together in all areas In general, Grumman concentrated on overall study management, orbiter design, analysis of mated configurations, and development test planning Boeing concentrated on booster design, ground operations, and maintenance planning The other team associates and their major areas of participation are shown in the accompanying figure



The initial phase of the study was directed toward definition and comparison of promising alternatives to the fully reusable concept including stage-and-one-half, expendable first stages, and variants of the two-stage reusable system This culminated in a configuration recommendation at the study mid-term point to pursue an External LH_2 Tank Orbiter/Heat Sink Booster configuration The remainder of the study was devoted to generation of detailed design, operational, and cost data for the selected candidate such that meaningful comparisons with internal tanked orbiter/TPS booster configurations could be made

During subsequent effort, both two and three-engined orbiters embodying the External Hydrogen Tank/Heat Sink Booster concept were compared to a representative internal hydrogen tank configuration Results were reviewed by NASA in March and April, 1971 As an outgrowth of these reviews, Grumman/Boeing were authorized to emphasize study of a Three-Engined External Hydrogen Tank Orbiter/Heat Sink Booster utilizing 415K sea level thrust engines It is this configuration, designated H-33, which forms the basis for the technical, cost, and programmatic documentation submitted in fulfillment of the ASSC contract

As part of the contract effort, a detailed design and cost comparison was made between the H-33 and a conventional internal LH_2 tank orbiter/TPS booster designated G-3 Results of this comparison show the H-33 to be significantly lighter, simpler, and less costly than its internal tank counterpart Gross liftoff weight is reduced by 30%, and wetted area is reduced by 16% and 30% on orbiter and booster, respectively The highlights of the H-33 configuration and its operational characteristics are summarized on the following pages



H-33 LAUNCH CONFIGURATION

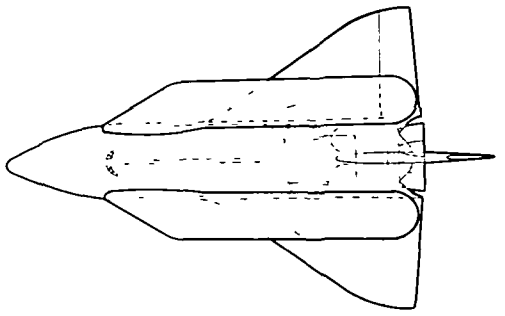
- OLOW 1,101,260 LB
- BLOW 2,824,000 LB
- GLOW 3,925,260 LB
- V_{STAGE} 7000 FPS

The H-33 Orbiter and Booster are mated in a belly-to-back configuration via two centerline attach/separation points which span the booster LH_2 tank Lateral mounting stability is provided by aft-mounted outboard pressure pads Two hydraulically actuated mechanical linkages, recessed in the booster body to minimize the booster-orbiter air gap, provide positive separation at staging A forward fairing between the vehicles significantly reduces interference heating

Common 415,000 lb thrust (SL) engines are installed in orbiter and booster, which employ 3 and 12 engines, respectively The engines are throttleable to 50% and gimbal to provide control during launch and insertion The air breathing propulsion systems (ABPS) comprise the currently available JTF-22A-4 in both orbiter (4) and booster (8)

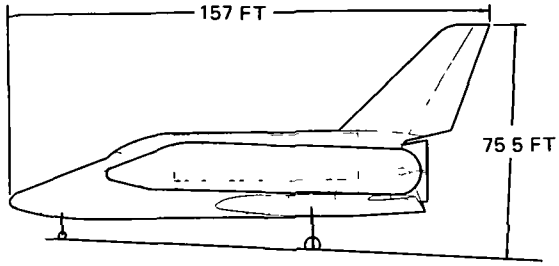
The more modest size and lower gross liftoff weight (GLOW) of the configuration is a product of the external LH_2 tank orbiter design concept

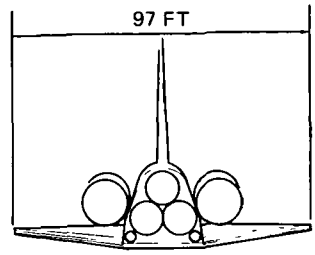
- The external LH_2 tanks permit high orbiter delta-V coupled with low core vehicle size and weight
- The improved orbiter structural efficiency causes the mated vehicle weight to optimize at a low staging velocity (7000 fps)
- The low staging velocity results in a low (227 n mi) booster flyback range, reduces booster size, and permits 100% Heat Sink Booster construction



H-33 ORBITER CONFIGURATION

PAYLOAD UP/DN (POLAR)	40,000 LB
INJECTION WEIGHT (W/O TANKS)	268,660 LB
INJECTION WEIGHT (W/TANKS)	292,260 LB
LANDED WEIGHT	241,172 LB
MAIN PROPELLANT	809,000 LB
LIFTOFF WEIGHT	1,101,260 LB
MAIN ENGINES, 3 @ T_{VAC}	477,000 LB
T/W	1 30



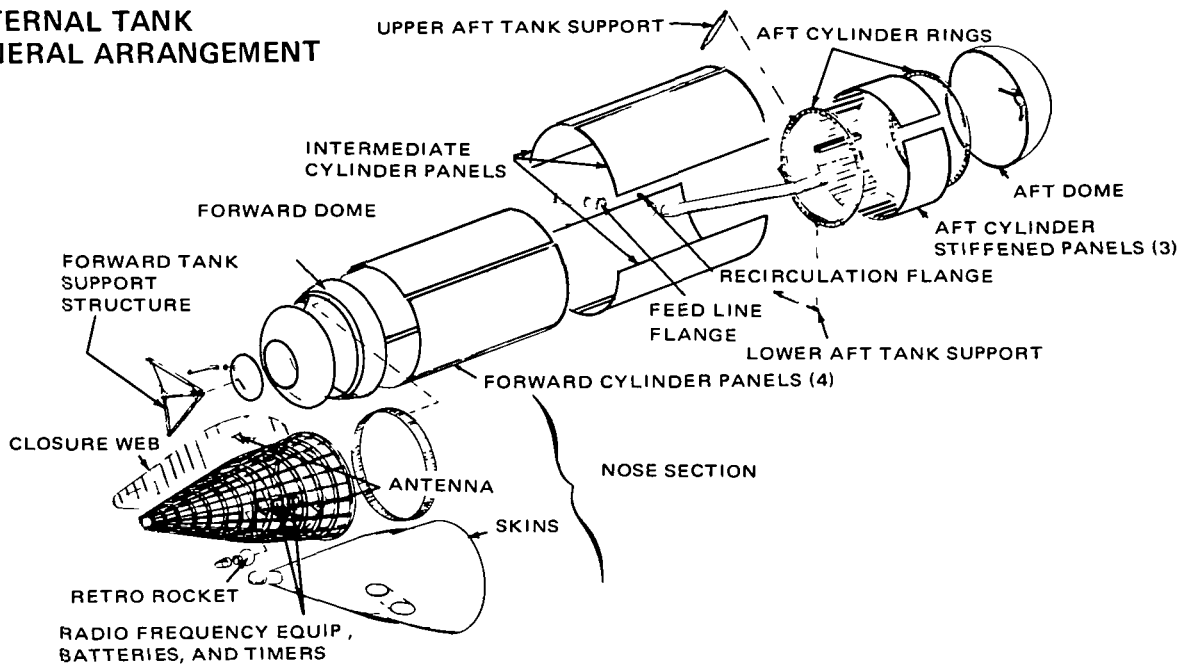


The H-33 Orbiter is a compact delta wing/centerline fin configuration carrying main propulsion LH_2 in two side-mounted jettisonable tanks Tank nose fairings reduce drag and interference heating during launch The rocket propulsion installation comprises three 477,000 lb vacuum thrust engines (415K SL) for insertion, two 15,000 lb thrust RL-10 engines for on-orbit/de-orbit maneuvers, and thirty 1000 lb thrust ACPS engines for fail-op/fail safe attitude control during orbital operations and reentry

Aerodynamic control is provided by full span elevons and a segmented split rudder which is flared ±30 deg for supersonic directional stability and for drag modulation (lower segment only) during landing The vehicle meets the 1100 n mi cross-range requirement and is stable over the flight regime Configuration design characteristics are·

- Constant body cross-section over 16 ft diameter x 65 ft long payload bay
- Payload bay position yields small in/out cg shift (0 7% body length)
- Air breather installation comprises two pairs of deployable JTF-22A-4 off-the-shelf engines, in/out cg shift 0 5% body length, removal yields two 5 x 10 x 13 75 ft compartments for alternate use
- Non-integral twin 11 ft D x 60 ft L oxidizer tanks are simply supported and removable for repair and refurbishment via the nose section manufacturing break
- 990 cu ft crew compartment houses four man crew plus EC/LSS, avionics and EPS Direct access to payload bay via airlock
- Thermal protection uses standoff insulated panels except for carbon/carbon on nose, leading edges, and elevon trailing edge
- Landing system comprises dual wheel nose and main gear plus twin 30 ft D drag chutes Gear rotates aft for deployment, aero blowdown provides second-tier backup

EXTERNAL TANK GENERAL ARRANGEMENT



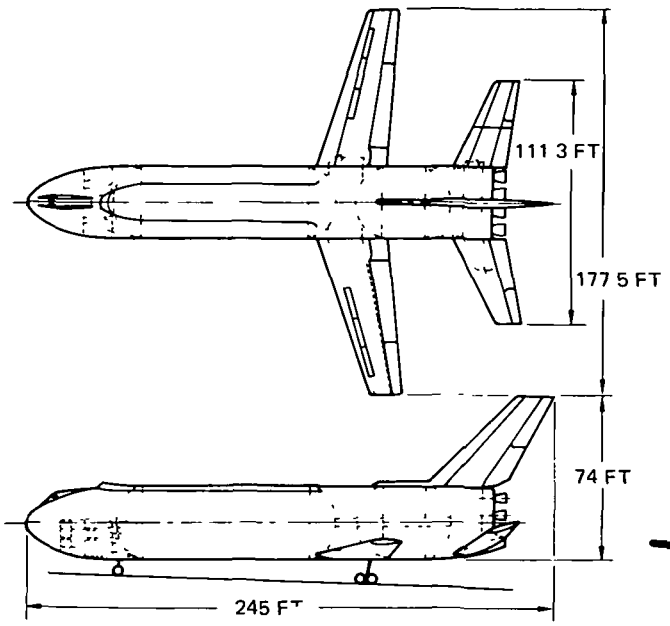
Each external tank is a 14 8 ft D cylinder with simple conical/hemispherical forward/aft end domes LOA is 102 ft including the 17 6 ft aluminum allow sheet-frame-stringer nose fairing The tank shell is a welded monocoque structure of 2219 aluminum alloy sheet, 0 057-in thick between weld lands LH_2 capacity each tank is 59,394 lb, dry weight is 10,349 lb/tank

A 0.75-in thick external layer of spray-on NOPCO BX250A foam provides cryogenic insulation Spray-on Pirex 250 ablator, 0 1-in thick, protects the tank inboard surface against interference heating Nose fairing and strut thermal protection is afforded by an Avcoat 5026-39 ablative cover

Attach struts are located at the forward and aft ends of the tank Separation is effected by release of three marman-type clamps via triply redundant explosive bolts plus initiation of two pyrotechnic actuators, which thrust the tanks laterally with a total impulse of 1460 lb-sec/tank All hardware is retained (no "shrapnel")

The redundant receiver decoders, timing circuits, and batteries used to initiate the tank de-orbit burn are located in the nose fairing together with the 10,000 lb thrust de-orbit SRM A burn time of 7 sec imparts 200 fps de-orbit delta-V to the tank Key points of this design approach are

- Existing technology applicable aluminum/LH_2 compatibility plus use of S-II spray-on foam insulation and ablator
- Simple fabrication untapered cylinder, simple end caps, no integral webs
- Decoupled development from basic orbiter structure
- Volume growth potential with minimum impact
- Fracture mechanics/flaw growth issue avoided
- Reusable cryogenic insulation development issue avoided
- Post-flight LH_2 tank purging and inspection eliminated



H-33 HEAT SINK BOOSTER

BLOW (POLAR)	2,824,000 LB
BURNOUT WEIGHT	575,000 LB
LANDED WEIGHT	520,000 LB
MAIN PROPELLANT	2,249,000 LB
MAIN ENGINES 12 @ T_{SL}	415,000 LB

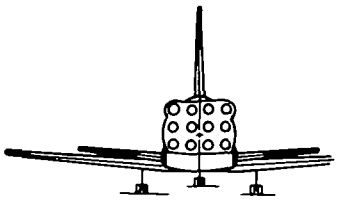


FIG 9 1 1 H 33 HEAT SINK BOOSTER CONFIGURATION (MODEL 979 124)

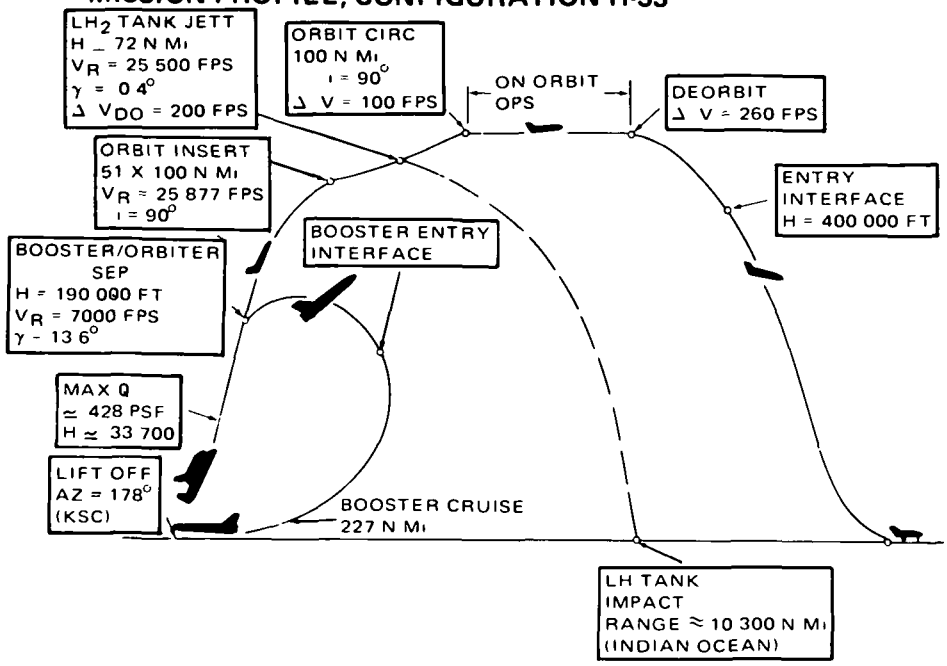
The H-33 booster is a conventional straight wing configuration powered by twelve 415 K lb SL thrust rocket engines plus eight air breathers for flyback The 218 ft long x 33 ft diameter body contains a two-man crew compartment, buried air breathers with deployable inlets and recessing exit doors, primary propulsion tankage and engines, and the accessories/consumables required for its 60 minute mission

Booster design employs 100% heat sink structure The LH_2 tank is a 2219 aluminum alloy cylindrical shell with integral internal waffle stiffening and 70% elliptical end domes Internally bonded PPO foam maintains initial LH_2 tank temperatures at -220°F and -100°F on heads and cylinder, respectively The 2219 aluminum alloy LO_2 tank incorporates internal "T" stiffeners and anti-slosh baffles Its aft location reduces fuselage structural weight, eliminates geysering, minimizes Pogo susceptibility, and accommodates straight-through passage of the wing carrythrough structure.

The wing and all-moving stabilizer are conventional two-spar aluminum alloy structure with titanium leading edges and control surfaces Haynes 188 structure sustains plume impingement heating on the fin leading edge at orbiter separation Flight attitude control utilizes boost engine gimballing during launch, 34 ACPS thrusters during coast and entry, and activation of control surfaces for flyback Significant design characteristics are

- 100% heat sink construction eliminates TPS panel development and refurbishment. Smooth surfaces minimize slot/protuberance heating
- Saturn technology and tooling are directly applicable to tank design
- LH_2 leaks are readily detectable (visible frost ring)
- Air breather booster accommodates JTF-22A-4 or the B-1 engine Development status, commonality, and availability dictates JTF-22A-4
- Aerodynamic configuration stable/controllable through flight regime, accommodates 30 kt cross wind at landing

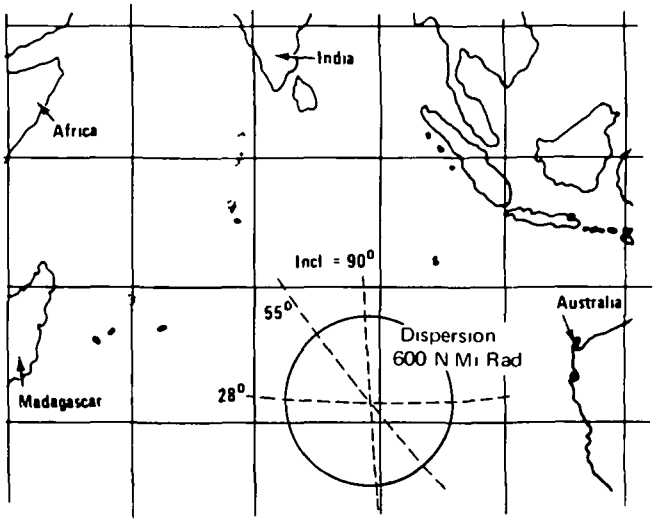
MISSION PROFILE, CONFIGURATION H-33



A typical mission profile for the H-33 configuration is shown above Significant events are summarized below, using values representative of a polar launch

- Vehicle liftoff is accomplished vertically with an initial T/W ratio of 1.27. Vehicle GLOW is 3.93 M lb
- Maximum dynamic pressure (q) of 428 psf is encountered at an altitude/velocity of 33,700 ft/1051 fps, 76 2 sec after liftoff
- Separation occurs 181 4 sec after liftoff at an altitude/velocity of 190,000 ft/7,000 fps Flight path angle and q are 13.6 deg and 18 4 psf, respectively
- Booster entry/flyback includes coast to 235,000 ft apogee, trim to 60 deg entry alpha, initiation of 90 deg bank at q max (111 psf), start transition at 30,000 ft (wings level) and start 227 n mi flyback at 16,000 ft Maximum normal load factor is 3 5 g, approach/landing speeds are 161/155 kt, respectively
- Orbiter insertion into a 51 x 100 n mi orbit requires a burn time of 275.5 sec with an initial T/W of 1 3 Insertion velocity is 25,877 fps
- External tank jettison occurs 20 min after orbiter burnout at an altitude/velocity of 72 n mi/25,500 fps Tanks are separated at an orbiter attitude of 30 deg nose up, 20 sec later ignition of the de-orbit SRM's is initiated via rf link, impact is 10,300 n mi downrange at 30 deg South Lat/90 deg East longitude (Indian Ocean)
- Orbiter entry is initiated with a 130 sec burn oriented 0 deg to the local horizontal Entry alpha is 27 deg The vehicle is controlled to thermal boundaries down to 1/2 circular velocity with subsequent control to a latitude/longitude target Maximum q/normal load factor are 260 psf and 1 28 g, respectively Full aero surface control is initiated at M = 4, approach/touchdown speeds are 240/180 kt, respectively

EXTERNAL TANK ENTRY DISPERSIONS



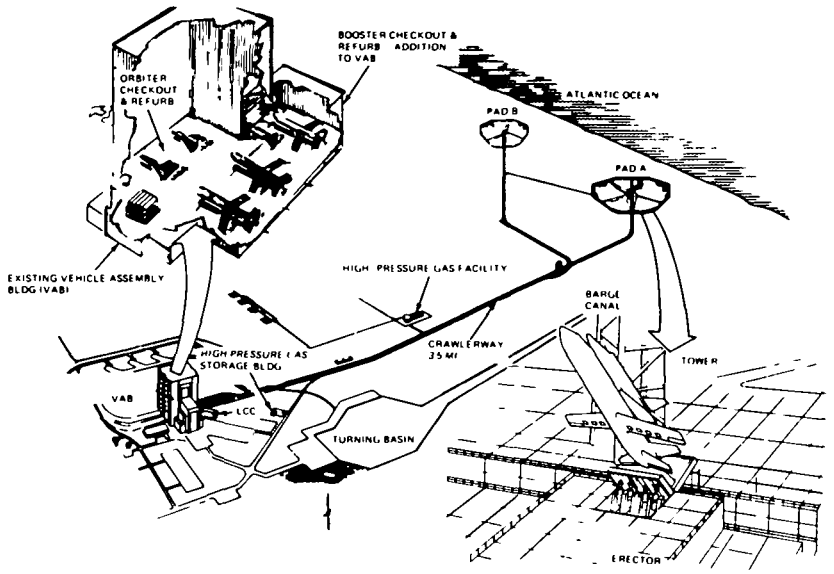
Impact areas and dispersions predicted for the baseline external hydrogen tank disposal system are shown above for KSC launches The impact zone for KSC reference missions is confined to a single region in the South Indian Ocean, approximately 1500 n mi west of Australia Impact for polar and retrograde launches from WTR occurs in the Pacific ocean at 60 deg S latitude, north of the Antarctic land mass

No attitude control system is required on the tank Dispersion analyses considering variations in orbiter alignment, tank cg location, attitude, and separation/de-orbit system hardware characteristics show an in plane error of 6 5 deg in the de-orbit velocity vector Resulting impact dispersions of surviving particles for a tumbling tank with a breakup altitude of 300,000 ft are ± 600 n mi downrange, ± 18 n mi crossrange

Predicted ship traffic densities for 1980 indicate that four ships, out of a possible 29,000 at sea, will be in the approximately 40,000 sq mi elliptical impact area For any mission, the resulting probability of any one particle impacting a ship is less than 1×10^{-7} Summarizing the characteristics of the disposal system

- External LH_2 tank materials and design approach encourage tank breakup and fragment burnup during entry
- Selected impact regions are remote from high density shipping lanes
- Impact dispersions are acceptable without active tank attitude control

GROUND OPERATIONS



Orbiter and booster are initially barged from the Michoud assembly area with wings and tail surfaces disassembled Final assembly is accomplished in the vertical assembly building (VAB) at KSC. Subsequent ground operations encompass all maintenance, checkout, mating, and launch operations required on booster, orbiter, and payload from touchdown through launch of the next mission The ground operations concept is directed toward eventual achievement of "airline type" operating practices utilizing onboard checkout/monitoring provisions Key events in the operations cycle are

- Subsystem and system checkout takes place in the VAB Subsystem tasks comprise visual inspection, scheduled/unscheduled maintenance, and hardware functional checks System verification of orbiter and booster will be performed to ensure preservation of interface compatibility Orbiter system testing will be preceded by mating of external LH_2 tanks

- Vehicle mating will be accomplished in a horizontal attitude by positioning the orbiter on the booster via a two-point suspension two-crane operation Mating and interface verification will be followed by payload installation

- Transfer to the pad will be accomplished by a 747-type tug, which tows the shuttle on the booster landing gear to the pad and positions it on the integral holddown/erector The holddown clamps are secured to the booster, and the vehicle erected to the launch position

- Final checkout and launch comprises propellant loading, crew and passenger boarding, final status checks by onboard avionics, system pressurization, and switch to internal power Booster main engines are ignited, upon verification of thrust buildup, the holddown arms are released for liftoff

H-33 ALTERNATE MISSION CAPABILITY (VEHICLES SIZED FOR 40K PAYLOAD TO POLAR ORBIT)

MISSION	OMS DELTA-V REQUIRED* (FPS)		PAYLOAD CAPABILITY (K LB)
	NOMINAL	ABORT **	
POLAR - 90 DEG	810	795	40
RESUPPLY - 55 DEG	1690	720	26 2
DUE EAST -28 5 DEG	1190	695	65 7

* ORBITER CARRIES MAXIMUM OF MISSION OR ABORT OMS DELTA-V

** INCLUDES 120 FPS FOR ENTRY ACPS MANEUVERING

Shuttle requirements specify the following orbiter payload capability for the three reference missions

- Polar 100 n mi Orbit 40 K lb up and down (no ABPS)
- 55° Inclination 270 n mi Orbit 25 K lb up and down (with ABPS)
- Due East 100 n mi Orbit 65 K lb up, 40 K lb down (no ABPS)

Also required is orbiter once-around abort capability in the event of an inoperative main engine at separation The abort is accomplished by operating the remaining engine(s) at emergency power in conjunction with a parallel on-orbit maneuvering system (OMS) burn during insertion, followed by a passive entry and return to site

The capability afforded by the three-engined H-33 configuration in meeting both payload and abort requirements is shown in the above table, which summarizes payload capacity and OMS nominal and abort delta-V requirements for the three reference missions The following characteristics are noted

- H-33 provides a close payload match for all three reference missions. The vehicle is sized by the polar mission 40 K lb payload requirement As indicated in the above table, the payload capability for the remaining reference missions corresponds closely to the requirements
- H-33 OMS propellant quantity is not penalized by abort requirements This is a consequence of the three-engined installation, which reduces the OMS abort requirement for the engine-out case below the OMS delta-V required by the nominal missions

TRADE STUDY SUMMARY

ENGINEERING		MANUFACTURING	12
• STRUCTURES/TPS	20	GRND OPERATIONS	3
• G&C/AERO/THERMO	21	TEST	2
• PROPULSION	8	TOTAL - 82	
• AVIONICS/ELECTRICAL	5		
• *ECLSS/CREW ACCOMM*	7		
• PAYLOAD INTEGR/SAFETY	3		
• VEH OPTIMIZATION (V STAGE)	1		

Eighty-two major tradeoff studies have been performed in support of the External LH_2 Tank Orbiter/Heat Sink Booster system definition, including 65 in engineering, 12 in manufacturing, and 5 in operations and test While they are by no means an exhaustive collection of studies, they have served to provide a reasonable degree of system optimization and maturity, particularly with respect to vehicle design characteristics, where the greatest emphasis has been placed

Certain significant factors have not as yet been subjected to tradeoffs, but have been accepted as groundrules these include the payload and mission performance requirements, the operational program schedule and traffic model, the use of KSC as the launch site, and the approach to transonic/supersonic flight test prior to FMOF

Of the total number of tradeoff studies tabulated above, 58 have been formally published prior to completion of the study The remainder are documented in the ASSC final reports

SYSTEM SUMMARY COMPARISON - POLAR MISSION

	H-33 3 ENG EXT TK		G-3 2 ENG INT TK		G-3 VS H-33 DELTAS	
	ORB	BOOST	ORB	BOOST	ORB	BOOST
WEIGHTS, LB						
• GLOW	3,925,260		5,240,920		1,315,360	
• OLOW/BLOW	1,101,260	2,824,000	938,280	4,302,640	-162,980	1,478,640
• INJECTION PROP	809,000	2,249,000	632,275	3,348,470	-176,725	1,099,470
• DRY WT STAGE	197,238	494,870	220,135	798,448	22,897	303,578
TANKS (2)	20,698	-	-	-	-	-
TOTAL	712,806		1,018,583		305,777	
DIMENSIONS						
• LGTH OVERALL, FT	157	245	173	296	16	51
• SPAN, FT	97	177 5	101 7	221 3	4 7	43 8
• WETTED AREA, FT^2	17,930	33,794	21,350	47,767	3,420	13,973
PROPULSION						
• PRIMARY NO ENG/ THRUST	3/477 K (VAC)	12/415 K (SL)	2/632 K (VAC)	13/550 K (SL)	-	-
• AIR BREATHERS	JTF-22A-4(4)	JTF-22A-4(8)	JTF-22A-4(4) (2 W/AB)	B-1 (10)		
PERFORMANCE						
• STAGING VELOCITY, FPS	7,000		9,750		2,750	
• ORB IDEAL DELTA-V, FPS	19,600	-	16,538	-	-3,062	-
• FLYBACK RANGE, NM		227	-	368		141

The purpose and intent of the ASSC study has been to define and develop a promising alternative to the fully reusable internal tank orbiter/TPS booster configuration, to a depth which permits meaningful comparison of design concepts The study has culminated in a detailed definition of the H-33 External Tank Orbiter/Heat Sink Booster configuration, which has been compared on technical, operational, and cost bases to its counterpart, the internal tank orbiter/TPS booster G-3 configuration

The above table lists major characteristics of each vehicle in sufficient detail to contrast key differences Weight and performance values shown reflect the polar mission, which sized both vehicles The comparison clearly identifies the advantages of the Three-Engined External Tank Orbiter configuration

- Higher Orbiter Delta-V H-33 provides 3,000 fps more insertion delta-V at an all-up (tanks included) dry weight 2200 lb less than G-3 This characteristic results in system weight optimization at a reduced staging velocity, which benefits booster design as cited below

- Lower Staging Velocity The H-33 7000 fps staging velocity is 2750 fps less than that of G-3 The resultant reduction in boost propellant and flyback range yields a smaller (delta gross weight 1.48 M lb) booster and permits full exploitation of the heat sink approach to booster design Booster TPS panel design, development, and operational refurbishment are thereby avoided

- Reduced Dry Weight H-33 is 306,000 lb (30%) less than G-3 in all-up dry weight, with an attendant decrease in overall dimensions and wetted area as tabulated above This characteristic eases handling and erection requirements as well as inspection and refurbishment of vehicle outer surfaces

- Lower GLOW H-33 gross liftoff weight is 1 32 M lb (25%) less than G-3 Substantially less boost/ injection propellant (922 K lb) is required, liftoff is accomplished with twelve 415 K lb thrust engines as opposed to thirteen 550 K lb thrust engines

As the above summary indicates, application of the external LH_2 tank approach to shuttle design results in orbiter and booster configurations which are smaller, lighter, simpler, and hence less costly than their internal tank counterparts

* * *

The foregoing introduction has provided a brief description of the Grumman/Boeing External LH_2 Tank Orbiter/Heat Sink Booster Shuttle configuration, its operational characteristics and its capability The following page contains a Study Volume Guide, which identifies the final documents submitted in fulfillment of the ASSC contract

Also listed are additional documents developed under the Grumman/Boeing Bid and Proposal effort currently underway in anticipation of proposals for a Space Shuttle System industry competition. These documents represent an interim stage in the Bid and Proposal preparation effort, and as such, are submitted at this time for NASA's information only

ASSC STUDY VOLUME GUIDE

A	ASSC Contract Documentation	Vol I D	Grumman Doc No	NASA Doc No
1)	Final Report			
Part I	Executive Summary		B35-43RP-11	MSC-03809
Part II	Technical Summary		B35-43RP-12	MSC-03810
	Vol I Shuttle Definition	A		
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ORBITER MANAGEMENT

Section 1

ENGINEERING AND DEVELOPMENT PROGRAM SUMMARY

1.1 INTRODUCTION

During the Alternate Space Shuttle Concepts study program, each technical discipline has evolved, as an inherent part of its study task, a definitive plan for satisfying the development requirements of the program. These individual plans have been iteratively reviewed and integrated to effect an overall approach which provides insight into timely satisfaction of the H-33 system design, analysis and requirements definition tasks. A major consideration in formulating this plan has been the approach to flightworthiness certification of the paper design. Our certification approach is an extension of the certification review process which was successfully evolved during the Lunar Module (LM) program. The approach is based on thorough technical specialist NASA/Grumman counterpart reviews within mutually acceptable program guidelines to establish, as the design evolves, a cost effective balance between analysis and test to provide the required degree of flightworthiness assurance. The establishment of equipment criticality on the basis of failure modes and effects analyses is crucial to the final establishment of each certification requirement. In this preliminary stage of planning it has therefore been necessary to pre-judge, to a degree, the outcome of the downstream certification reviews and on the basis of experience alone, define a baseline set of ground test activities. The Grumman team brings to the shuttle program a currency of applicable technical experience, through the LM, F-14 and other programs, which would be difficult, if not impossible, to match elsewhere in the aerospace industry today.

The baseline Engineering and Development Plan enables engineering itself and the supporting activities to get a handle on resources planning. It has been developed in sufficient detail to permit meaningful NASA counterpart critiques - many of which have already been initiated. The mutual benefit of these critiques (which practically speaking are, at this point, only the beginnings of processes which will continue throughout the program) has been amply demonstrated by the outstanding results achieved by the NASA/Grumman cooperative effort on the LM program.

The acknowledged soundness of Grumman's traditional conservative approach is evidenced throughout the plan. We stick to proven technology and demonstrated capability in preference to going after unobtainium unless it is clearly obvious that nothing else will do. This carries over into the seller area as well, since the easiest way to guarantee adequate seller performance is to define for him a possible task. Easing of main engine performance requirements is an outstanding advantage that the H-33 system offers in the GFE area relative to assuring program realism. The composite H-33 system benefits of smaller, lighter, simpler and lower cost are attractive system features in themselves, but, in the context of planning have the added plus of being "easier to plan and do".

1.2 SUMMARY

The Engineering and Development Plan is aligned to the NASA work breakdown structure (WBS) and therefore the effort of each technical discipline is presented in a separate section. Recognition of the importance of systems integration functions has led to the introduction of a few additional sections which could be considered for downstream modifications of the WBS.

To provide a comprehensive planning tool for in-house as well as NASA use, the following contents are included in the plan:

Systems Sections

- Task description and narrative plan
- Logic network
- Schedule
- Analytical techniques
- Commonality candidates
- Applicable facility requirements list
- Computer support requirements list

Subsystems Sections

- Functional description and narrative plan
- Logic network
- Schedule
- Certification plan

- Component list
- Hardware requirements list
- Commonality list
- Support requirements list
- Facility requirements list
- Computer support requirements list

Specific sections address in depth the proven engineering management techniques to be employed. Key development issues and plans for their resolution are highlighted in special sections of the volume as well as integrated into the appropriate specialist sections. These are relatively few in number because judicious selection of the design parameters of the H-33 shuttle system has effectively minimized development risk. Landing without LH_2 tanks for example obviates the need for developing and demonstrating a purge system that would be adequate to get that warm feeling about crew and passenger safety.

1.3 MAJOR PROGRAM ELEMENTS

The major elements in the space shuttle program are:

- Orbiter
- Booster
- Main engines
- Operation ground system
- Payload

The Engineering and Development Plan contains the logic and schedule for the design, development, analysis and ground test activity related to the following orbiter elements.

- Airframe (Section 3)
- Propulsion (Section 4)
- Avionic (Section 5)
- Power (Section 6)
- ECLS (Section 7)
- Payload Integration (Subsection 3.8 and Section 8)
- System Testing (Section 10)
- System Engineering and Integration (Section 2)
- Management (Section 1)
- Software Development (*Subsection 1.12)
- Flight Control System Integration (*Subsection 2.19)
- Wind Tunnel Test (*Subsection 2.20)

*Added to provide better definition of the design and development effort.

Facilities, system support and computer support are additional orbiter elements which require engineering inputs. Accordingly this plan includes engineering requirements for facilities in each system and subsystem section. Also, the engineering requirements for system support are included in each subsystem section and tabulated in Section 11. The engineering requirements for computer support are contained in each system and subsystem section and consolidated in Section 12.

1.4 DEVELOPMENT LOGIC AND SCHEDULE

Each system and subsystem section of this plan contains a detail logic diagram and schedule. The individual logic diagrams are summarized in Fig. 1.4-1. The individual schedules are summarized in *Fig. 1.4-2. The integrated orbiter development schedule, Fig. 1.4-3, combines the engineering, manufacturing and flight test planning in support of the space shuttle program.

These documents will be updated as the orbiter configuration is defined and will be used to monitor the orderly development of the program. The same constraints and time spans shown on these documents will comprise the initial inputs to the computerized Operational Data Management System.

*Inclosed inside the back cover of this volume.

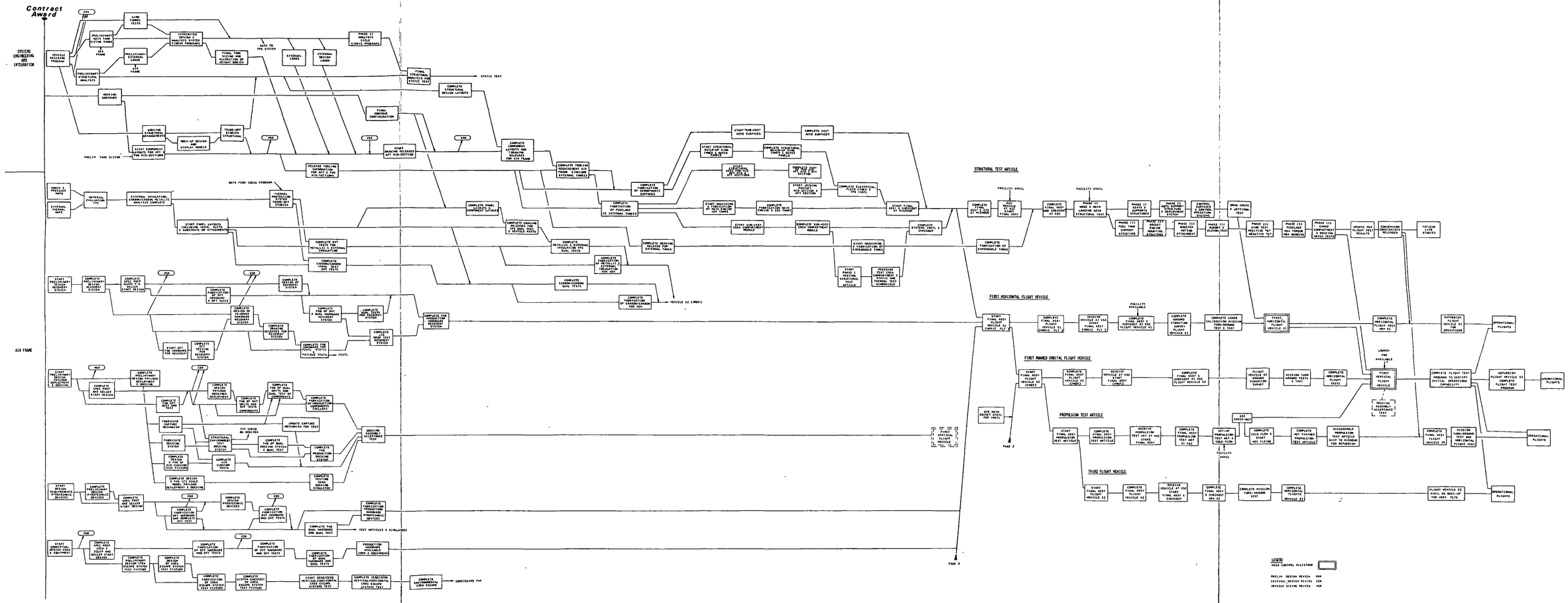

Fig. 1.4-1 Orbiter E & D Program Logic Network (Sheet 1 of 2)

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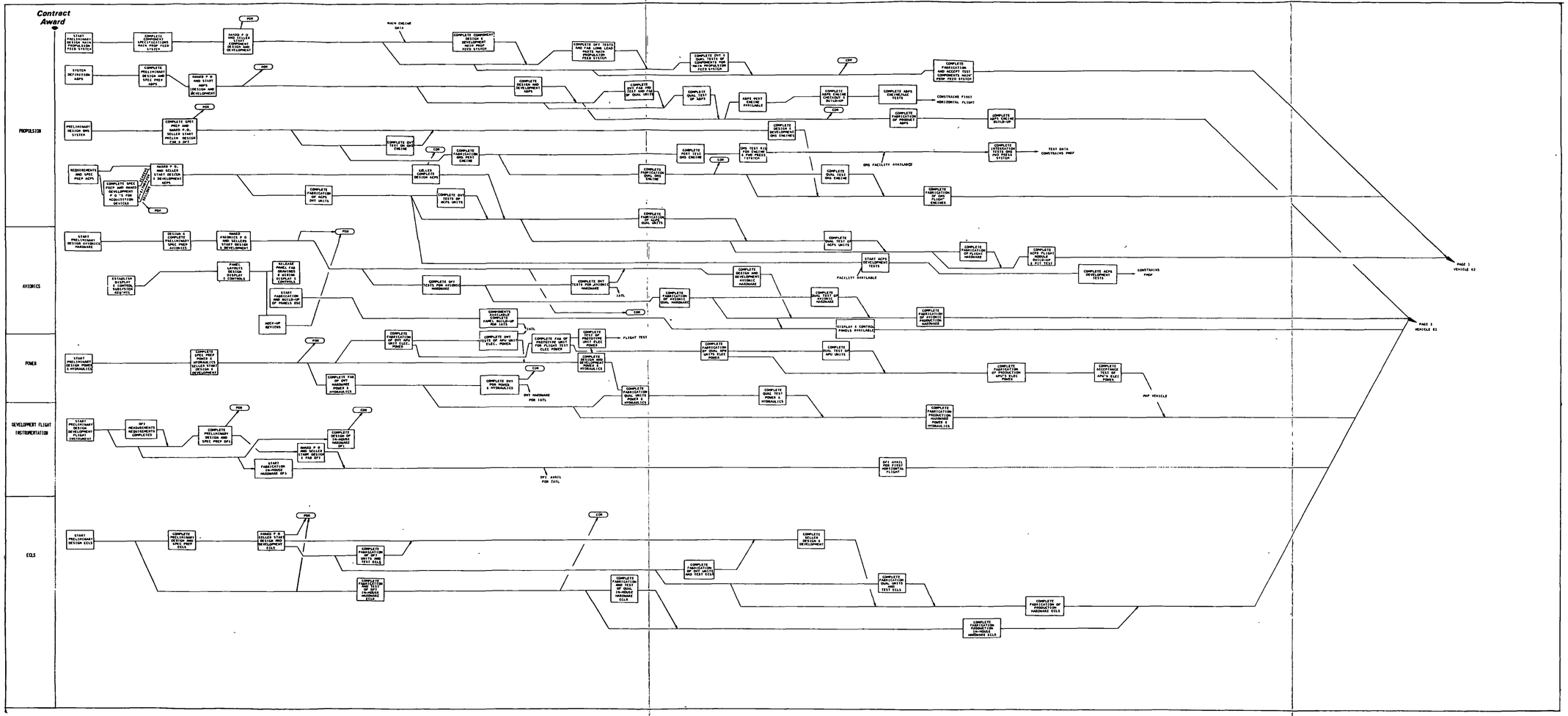

Fig. 1.4-1 Orbiter E & D Program Logic Network (Sheet 2 of 3)

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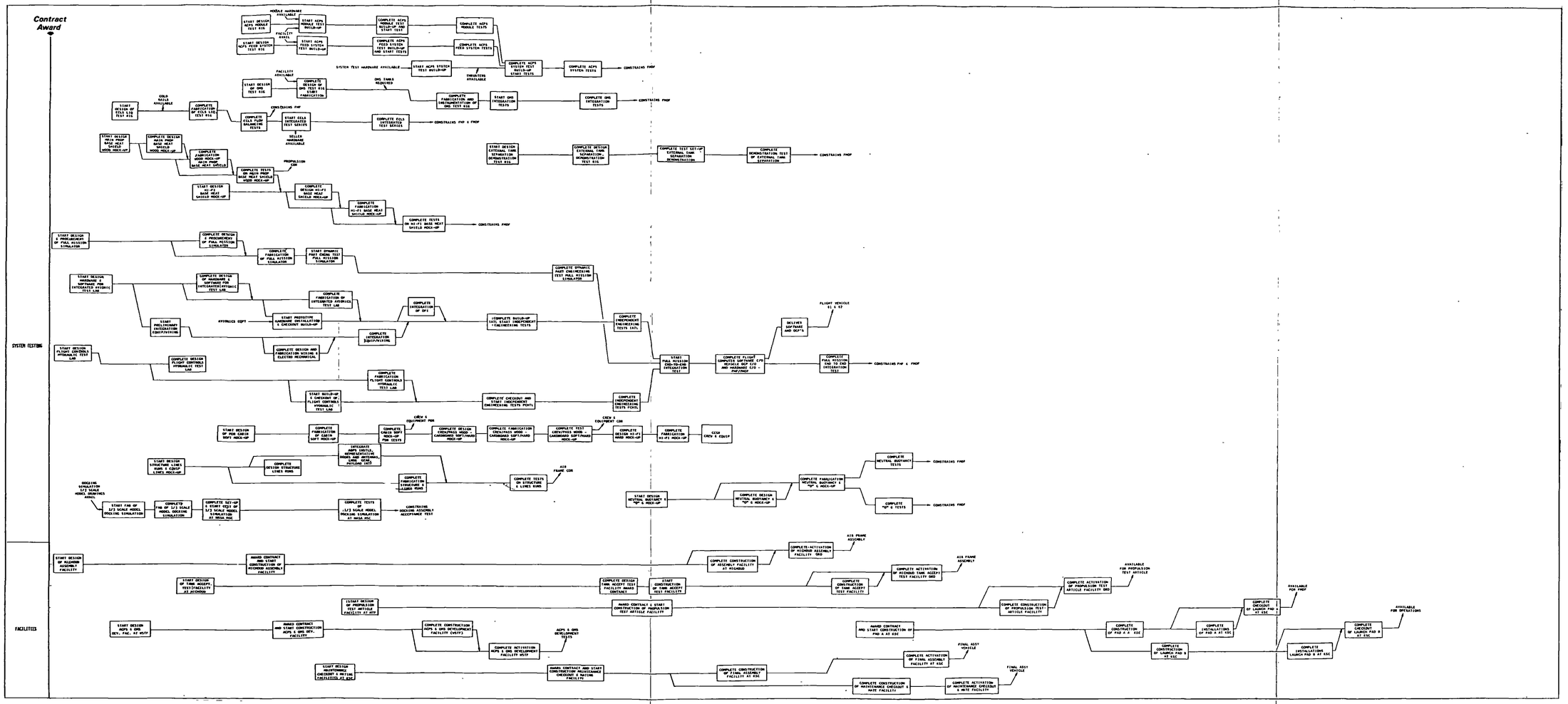

Fig. 1.4-1 Orbiter E & D Program Logic Network (Sheet 3 of 3)

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This figure is enclosed in an
envelope in the back of this volume.

Fig. 1.4-2 Engineering And Development Schedule

Fig. 1.4-3 Space Shuttle Phase C/D Master Program Schedule

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1.5 ORBITER ENGINEERING ORGANIZATION

1.5.1 RESPONSIBILITIES

The Engineering organization is responsible for:

- Design, analysis, simulation and development testing of:
  - Systems & Subsystems which comprise the flight vehicle
  - Test Articles
  - Mockups
- Definition & control of flight vehicle interfaces
- Definition & documentation of technical requirements:
  - Specifications
  - Drawings
  - ICD's
  - Seller Requirements
- Engineering configuration and change control
- Certification requirements definition and control
- Commonality requirements definition and control
- Mission analysis and mission support
- Off-site engineering

Figure 1.5-1 depicts the engineering organization we have set up to manage the Engineering and Development tasks. It blends the best features of our most recent major aircraft and space programs engineering management techniques. Most of the organizational

elements are in place and working at the present time in accordance with this organizational structure. It is working well and no difficulty is expected in transitioning into the phase C/D buildup.

Particular features of each of the major organizational elements are highlighted in the following paragraphs.

1.5.2 SYSTEMS

The groups that comprise Systems are those which establish requirements and which interface to a large extent with other technical specialities.

Systems Integration is placed under an Assistant Systems Leader. His group is responsible for preparation and updating of Interface Control Documents, tracking of commonality approaches between shuttle elements, and coordination of checkout requirements and criteria.

Flight Control Integration is also organized under an Assistant Systems Leader. The Assistant Leader has a small staff of technical specialists from Mechanical Design, Guidance & Control, Avionics Subsystem Design, Aerodynamics, Trajectory Analysis and Control, so that an integrated set of requirements and design philosophy is developed within the Systems section. Detail design to meet these requirements are carried out in the various technical specialty areas.

Software development for vehicle flight systems and coordination of engineering support software as described in Section 1.12 has been centralized in the Systems Section.

Reliability/Maintainability are functionally and administratively part of the Engineering organization. As on the LM program they are provided a direct reporting channel to Program Management.

Mass Properties is placed under Systems to provide continuous weight status and control, through an organization which is separate from those groups which design and analyze the hardware. This provides the Engineering Manager with an independent appraisal at all times. This was one of the contributing factors to our highly successful weight control record on the F-14 aircraft. Direct reporting to Program Management is also provided for this group.

Certification Requirements definition and control is placed in Systems Engineering as it is on the LM Program. Further definition of this group's task is in Section 2.5.

1.5.3 AVIONICS

The Avionics subsystem section provides the design and subcontract engineering control of electrical and electronic hardware. Its major development tool is in the Integrated Avionics Test Laboratory.

1.5.4 FLIGHT MECHANICS

This is an analytical and experimental technology section. It provides the analytical effort in aerodynamics and aerodynamic performance, loads and dynamics, handling qualities, reentry and ascent thermal environment, cryogenic analysis, overall vehicle thermal balance, trajectory analysis, and trajectory control laws. Simulation activity and wind tunnel testing described in Sections 2.14 and 2.20 are also managed from this Section.

1.5.5 VEHICLE DESIGN AND ANALYSIS

This section combines the design and analysis functions necessary for design of the body and aerodynamic surfaces of the vehicle. This is a departure from the approach used on LM where the structural design and analysis functions are separated. We found on our F-14 project that it is possible to keep the important check and balance features in an organization which combines the structural design and analytic work under a single Section Leader. This arrangement promotes rapid response and the good communications needed for an efficient development program.

This Section has the responsibility for defining structural criteria for vehicle structures, hydraulic and propulsion systems, and subcontracted equipment.

The Structural Temperatures/Thermal Protection System Group works from the external surface isotherms provided by the Thermodynamics Group and determines the temperature distribution through the vehicle as needed for structural design. The Structural Temperature and TPS work is so inter-related that we find this to be an excellent combination. This work feeds directly into thermal stress work within VD&A.

Because its major effort interfaces closely with the Structural Design and TPS groups, the Materials Group is also placed in Vehicle Design and Analysis. The material group work package provides support for all Engineering groups requiring materials engineering assistance.

1.5.6 PROPULSION

The propulsion technologies are grouped together under a separate Propulsion Leader due to the dominant nature of these subsystems on the orbiter configuration. Propulsion analysis and design efforts are grouped together for each of the subsystems. The Main Propulsion Group has responsibility for propellant tank pressurization and loading requirements. Tank structural design is carried out under the Vehicle Design and Analysis Section. Air Breathing Propulsion includes both cruise and special ferry propulsion.

1.5.7 MECHANICAL SYSTEMS

This design section is responsible for mechanisms, crew and passenger accommodation, environmental control and payload provisions.

The Mechanisms Group includes payload handling, flight control system mechanism, docking, vehicle and tank separation, and pyrotechnics or explosive devices.

1.5.8 ENGINEERING TEST

This section coordinates the requirements for the development and verification testing of the subsystems, the vehicles and the major ground test articles. It also plans and performs those tests not subcontracted to the subsystem vendors. The major ground test programs are described in Section 10.0.

The engineering test personnel that plan and conduct the development and qualification tests are used for the subsystem and system integration tests. Experience gained is applied to development ground test and checkout of the flight vehicles.

1.5.9 ENGINEERING OPERATIONS

This section is patterned after the similar group which has proved highly efficient during the last several years of the LM program. It is a gathering under a single manager of the primary Engineering control and service functions. It is here (under Resource Control) that the Engineering Work Packages are established and centrally administered.

1.5.10 ENGINEERING MANAGER'S STAFF

This small group provides direct support to the Engineering Manager for special tasks. It includes Configuration Schematics because a centralized task force similar to the LM "livewire" group is drawn from all engineering disciplines to develop a workable, properly interfaced, detailed design schematic for each subsystem.

1.5.11 ORBITER PROGRAM MANAGEMENT

Engineering is but one of several major organizational elements which work as a team to provide all of the functions necessary to a successful development program. Grumman's capability to pull together and get the job done is its greatest strength.

For the inter-relationship between orbiter Engineering and other orbiter organizational elements see Fig. 3-1 of the Management Volume.

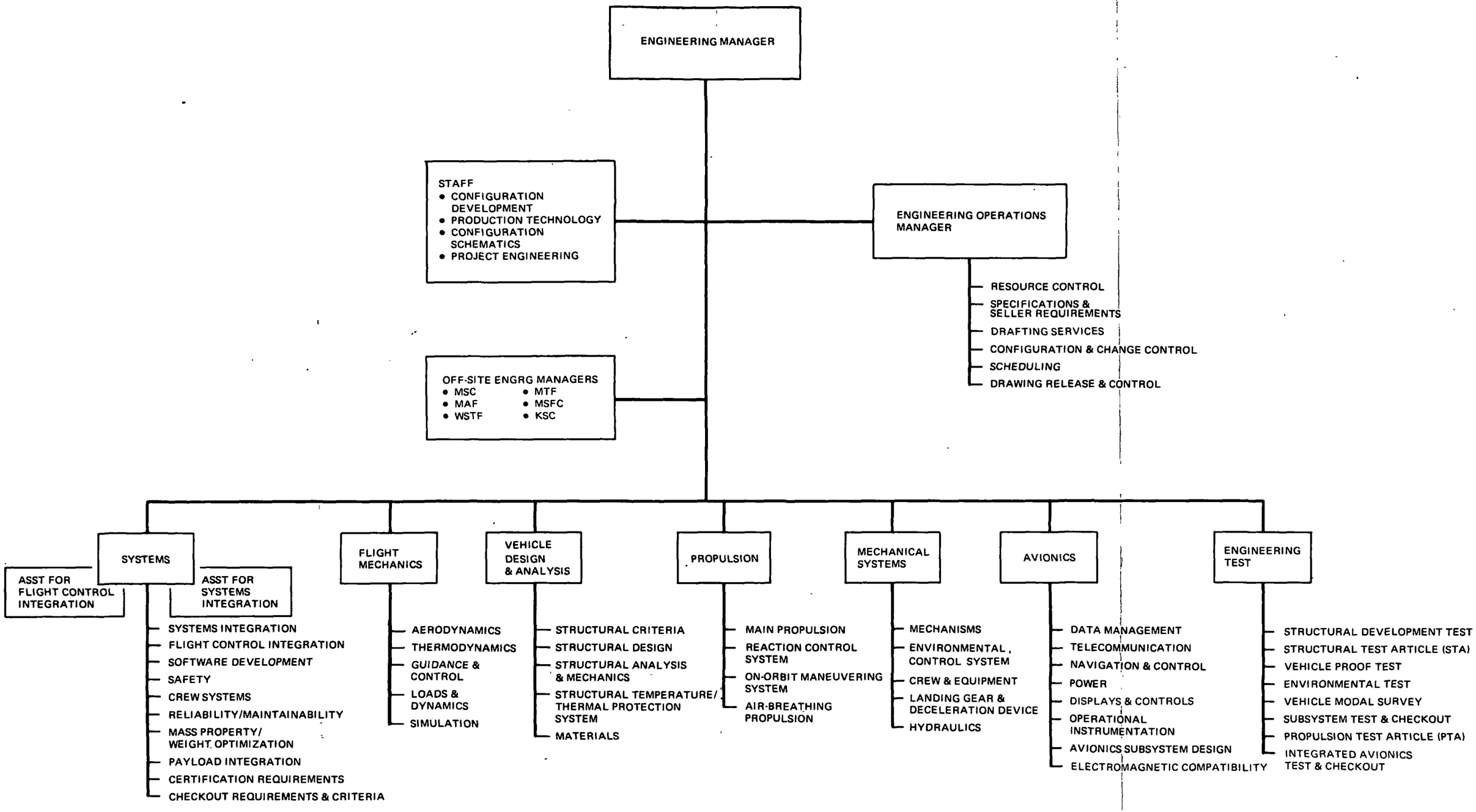

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Fig. 1.5-1 Orbiter Engineering Organization Chart

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1.6 ANTICIPATED TECHNICAL PROBLEMS/CRITICAL RISKS

For the H-33 external tank orbiter/heat sink booster there are relatively few areas where missing technology or serious technical problems create doubt in meeting planned engineering development schedules. Items which might place the schedule in jeopardy are labeled "critical technical risk items"; the approach on each of these is to create parallel or backup efforts to minimize risk to overall vehicle schedules. Critical technical risk items are those items which require missing technology (a new material, a breakthrough, an invention, etc.) for fulfillment; they include:

- Reusable high pressure engine (GFE to orbiter and booster)
- Reusable thermal protection system (TPS)
- Orbit maneuvering system (OMS) tanks
- Propellant acquisition devices

Difficult engineering development items are defined as those which require constant engineering attention but do not require a breakthrough or invention for fulfillment; among others, they include:

- Meeting target weights and mass factors
- LH_2 cryogenic insulation (booster only)
- Reusable cryogenic tanks
- ACPS conditioning equipment
- Pogo prediction and prevention
- Penetrations of the heat shield
- Insulation for 2500^{o}F
- Leakage prevention and detection
- Meeting reliability goals

- Low cost avionics design
- External tank engineering development issues

1.6.1 REUSABLE, HIGH PERFORMANCE, HIGH PRESSURE ENGINE

This GFE engine represents a significant advance in the state-of-the-art of current engine developments, the very high performance requiring nearly perfect combustion efficiency in a high pressure, staged-combustion-cycle engine. If the performance requirements are missed by as little as one percent, the vehicle payload is reduced by 1017 lb.

Since the engine must meet its performance and weight objectives, it is recommended that parallel developments on critical engine components (injector, turbopumps and thrust chamber) be initiated and continued through the completion of initial altitude performance firings at Tullahoma.

1.6.2 REUSABLE THERMAL PROTECTION SYSTEM (TPS)

For temperatures in the 1800 to 3000^{o}F range, there are no existing thermal protection systems capable of meeting the shuttle TPS weight and reusability requirements. To cope with this problem the following steps are taken:

- Non-metallic, external insulation (EI) is developed as the primary TPS for use in the 1600 to 2500^{o}F range. Emphasis is placed on improving its physical properties to withstand thermally-induced strain, and making it moisture resistant
- Metallic, re-radiative, Haynes 188 panels are carried as a backup to the EI for the 1600 to 1850^{o}F range until test data is available to indicate that the EI can meet the reusability and weight requirements
- Panels of both metallic and non-metallic TPS are installed on the horizontal flight test vehicle to determine the resistance to moisture and erosion from rain and sand and dust
- Metallic, re-radiative, coated columbium panels are carried as a backup for the 1800 to 2200^{o}F range, again until EI data is available

- Oxidation resistant carbon/carbon is developed as the primary TPS in the 2500 to 3000^{o}F range. Emphasis is placed on improving its physical properties and resistance to the abrasive effects associated with its location on leading edges, nose cap, etc

- Ablative panels for leading edges and nose caps are carried as backups to the carbon/carbon until data on carbon/carbon is available to indicate that it can meet the weight/reusability requirements

1.6.3 ORBIT MANEUVERING SYSTEM (OMS) TANKS

The purge bag tank is the primary approach because it is lighter than the standard ring-stringer dewar design. However, since the cold multilayer insulation (MLI) is exposed, purging is required during operation in the atmosphere (ground hold, ascent, reentry and landing) to eliminate air liquefaction and frost formation. The ultimate use of the purge bag tank requires solution to a number of practical problems such as:

- Design of an effective purge-bag system which minimizes the purge gas usage rate but does not compromise the requirement of the MLI for an interstitial pressure of less than 10^{-4} torr

- Design a purge gas distribution system that precludes local frost formation inside the blanket

- How to ensure the in-space MLI thermal performance during ground hold and reentry when the primary thermal protection during this time is based on the foam insulation

Since the purging system represents a weight penalty and decreases the reliability of the MLI for multi-mission use, a strong parallel program is undertaken to develop a lightweight outer shell dewar; the Grumman tension membrane design is the primary candidate. This design resists pressure over large areas by using the material in tension with intermediate compression rings carrying the transverse component of the membrane loads. The potential weight savings (especially for tanks with an L/D greater than one) is several hundred pounds over the purge bag system. It is expected that the tension membrane-dewar, already a strong candidate for the OMS tank, will become the primary approach prior to the start of Phase C/D.

A common problem to both tanks is how to route vacuum-jacketed feedlines from the tanks to the OMS engines and keep the lines empty until OMS engine firings. The primary approach is to mount shutoff valves on the tanks within the highly insulated region. The startup problem requires additional studies to overcome surge conditions upon contacting the warm lines with the cryogenic fluids.

1.6.4 PASSIVE PROPELLANT ACQUISITION DEVICES

The use of capillary devices (screens) is selected as the primary approach because they are simple, passive devices and lighter in weight than bellows. The following practical problems must be overcome in implementing this approach:

- Sensitivity to orientation relative to adverse acceleration forces due to RCS engine firings
- Subcooling liquid flow channels
- Providing NPSH to preclude bubble formation under screens
- Optimization of flow channel dimension to minimize residuals
- Procedures to fill tanks and verify the absence of bubbles under the screens at the conclusion of the loading procedure up to time of launch
- Procedures to clean retention devices after installation in tanks

Data for low gravity heat and mass transfer is available to solve some of the uncertainties mentioned above. Sloshing frequency and interface stability are modeled for on-the-ground testing by proper scaling of the Bond and Weber numbers.

In view of the difficult problems which face the passive acquisition approach, a parallel development of an active propellant acquisition device (bellows) is being pursued. The problems which must be solved to make this approach acceptable are:

- A reduction in its weight and/or an improvement in its expulsion efficiency
- Improve bellows reliability by extending predictable cyclic life and resistance to vibration

- Definition of adequate inspection, servicing and checkout procedures
- Evaluation of impact of inflight refueling on orbital operations

1.6.5 MEETING TARGET WEIGHT AND MASS FRACTIONS

Since the solution to many difficult engineering development problems often involves added weight, and because inert weight growth impacts mass fractions, the single most difficult engineering development item is just that: the control of vehicle inert weight and mass fraction. To cope with this problem the following steps are taken:

- Establish realistic target weights and weight growth margins
- Provide timely and accurate design loads
- Electronic data processing weight accounting
- Weight engineers authority over engineering drawing releases
- All weight changes reviewed daily by program management
- Freeze GFE engine maximum limit weight early in program
- Delay orbiter external LH_2 tank sizing
- Provide volume for added internal LO_2 tanks in future
- Delay booster tank sizing

1.6.6 LH_2 CRYOGENIC INSULATION

For the H-33 external tank orbiter, the use of Saturn S-II type, NOPCO foam insulation (applied externally) is the selected insulation since it is fully developed, readily available, has a low conductivity and density and is adequate for the expendable tank. Qualified repair techniques are also available for local damage caused by multiple propellant loadings.

On the other hand, the integral LH_2 tank in the heat sink booster requires internal cryogenic insulation. For long durations or for multiple exposure, present candidates work on the insulating property of stagnant hydrogen gas entrapped in a plastic matrix.

Two basic approaches are carried: (a) the established, heavier Saturn S-IVB type 3D insulation is expensive and may degrade after multiple exposures to the 250°F reentry condition and, (b) PPO insulation maintains advantages in weight, and high temperature capability (350 to 390°F) but is unavailable in fully developed form. The bond system for either candidate is a problem and additional work is needed to develop an adhesive to meet the required strength over the temperature range.

Since both the 3D foam and PPO are likely to be a source of particulate contamination, a reusable/replaceable filter may be required for insertion in the booster LH_2 lines leading to the engine.

1.6.7 REUSABLE CRYOGENIC TANKS

The problem is how to design, fabricate, test and verify the structural adequacy of lightweight tankage pressure shells for the 100 mission requirement.

Materials evaluation and screening resulted in the selection of Al 2219-T87 alloy, which has a high fracture toughness property. This characteristic, in addition to the thin shell gages, prevents complete reliance on fracture mechanics, proof-testing and NDE in screening flaw sizes which may grow to critical crack size during the 100 missions, without using higher factors of safety.

The solution selected for the Grumman H-33 orbiter is to use expendable single mission external LH_2 tanks, and removable internal LO_2 tanks which can be reproofed/ and/or reinspected. The approach is as follows:

- For the external LH_2 tanks, a GN_2 proof test is used to screen the tanks for the limited use requirement of these disposable tanks. The number of pressure cycles which is low is established in a materials test program
- For the internal LO_2 tank, a LN_2 cryogenic proof is used to screen the tanks. The proof test is supplemented by non-destructive evaluation (NDE) inspection techniques. The absence of insulation on the tank makes possible visual inspections of high stress regions. If necessary, the tank is removed and reproofed/ re-inspected or a replacement tank installed

- A multi-ply or overwrap, flaw growth retardant, tank study and materials investigation is carried in parallel with the LO_2 tank development on the basis that the weight saving or reduced maintenance cost makes it cost-effective to pursue the study

The approach on an internal tank orbiter is the same as on the external tank orbiter with the exception of the LH_2 tanks. For reusable LH_2 tanks, a LH_2 proof test is used to screen the tanks. Since the tanks are floating, they are removed and reproofed/reinspected, if necessary; for maximum effectiveness, the inspections require removal and re-installation of the external insulation.

The approach on the heat sink booster, where the tanks are integral and therefore not removable, is to design the tanks with a sufficiently high safety factor that they can be proofed to assure a safe life for 100 missions. To establish the required safety factor and proof pressure test requirements for each tank, a materials test program is conducted on Al 2219-T87 samples using both LH_2 and LO_2.

1.6.8 ACPS CONDITIONING EQUIPMENT CONTROL

The problem is that the life of the propellant conditioning equipment (turbopumps and heat exchangers) is greatly influenced by off-nominal operation, and by the sequencing of the startup and shutdown of each of these items.

The approach leading to certification of the conditioning equipment is as follows:

- The conditioning system design minimizes interface coupling and has conservatism in performance levels
- Component and system dynamic models are used to identify transient and steady state behavior; data from these models are used to establish performance specifications and design requirements for control unit elements and devices
- Conditioning module tests are performed as early as possible in the program to identify control system characteristics

1.6.9 POGO PREDICTION AND PREVENTION

The primary dynamic problem in the ascent phase of the mission is Pogo. Although more of a problem on the mated configuration this airframe/propulsion system interaction requires careful attention to prevent occurrence of high g level oscillations on the orbiter. A detailed analytic mathematical model of the coupled booster-orbiter as well as the orbiter alone is used to obtain the highly coupled free-free modes of the respective configurations.

Significant propulsion items such as feedlines and engines are included in the math model. Pogo stability calculations are performed initially using transfer functions empirically derived for the engines to be used; based on this early analysis, modifications to the system are undertaken to improve vehicle stability. As the design matures, detailed tests are performed on critical propulsion items (engines, feedlines, turbopumps, and propellant manifolds) and critical structural elements to obtain dynamic response characteristics. This data is used to continually update the Pogo analysis to assure that the space shuttle is free from detrimental vibrations.

1.6.10 PENETRATIONS OF THE HEAT SHIELD

There are several unavoidable penetrations of the orbiter heat shield such as those caused by landing gear doors, gaps between TPS panels, ACPS thruster exits, vents, dumps and access ports. Each penetration creates several types of special problems: heating inside the cavity and at the downstream lip, local high heating zones due to flow disturbance over the surrounding TPS, premature boundary layer transition due to local effective roughness, and possible acoustic resonance in some types of cavities. The Grumman Research Department has conducted preliminary experiments on simulated thruster penetrations, finding internal heating as high as eight times the local undisturbed surface value, and external amplifications of greater than two. Recognizing this problem, NASA's Marshall Space Flight Center is currently selecting a contractor to conduct a technology study of thruster penetrations (PR DNC 1-1-50-13675).

In addition to the results of the above study, it is necessary to apply analysis and some shock tunnel and wind tunnel testing to each of the different types of penetrations designed into the vehicle.

To minimize testing, three important groundrules are issued to designers:

- Limit gap widths to as small a fraction of the local boundary layer thickness as possible
- Align slots either normal or parallel to the local flow field velocity during high heating portions of the trajectory (since oblique slots develop vortical flows that cause very high internal heating)
- Avoid the use of forward facing cavities or close them over with doors (since forward facing cavities usually develop highly unsteady flow systems in hypersonic environment)

1.6.11 INSULATION FOR 2500 TO 3000°F

The packaging of zirconia insulation in a moisture-proof metallic envelope is not practical since suitable oxidation-resistant metallic materials are not available. High temperature insulation should be protected from direct rain and liquid water contact; however, it is allowed by design to be in equilibrium with atmospheric moisture by the incorporation of deliberate venting provisions. Since zirconia is used only in very limited areas, such as nose caps and leading edge areas, desiccants are used during turnaround operations to remove any absorbed moisture. The primary approach, therefore, is to use zirconia mat or felt, protected from direct water impingement and held in position by lower temperature capability substrates.

1.6.12 LEAKAGE PREVENTION AND DETECTION

The problem is that maintainability reasons require fluid system mechanical joints which are heavy and can be a source of leakage. The approach is to (a) minimize the number of mechanical joints by packaging fluid system components into replaceable modules, (b) carry the development of lightweight seals for hydrogen and oxygen service as a potential weight savings and (c) where mechanical joints are used, provide for redundancy and detection of leakage between the redundant seals.

To resolve the problem of detecting leaks, a promising technique for the detection and location of leakage is acoustic emission. The Grumman Research and Quality Control Departments are presently working on the use of multiple detector systems with associated

computer signal analysis, that may provide real-time monitoring of tank condition. An automatic system is envisioned that senses the increased emission from a leak, and indicates its severity and location. Acoustic data from a reference tank with calibrated leaks would be used for baseline comparison. A significant effort is required to achieve this ultimate system. The program presently underway is using small pressurized diaphragms with induced cracks. A logical sequence of development is to go to large diaphragms before proceeding to small, then large, tank configurations.

1.6.13 MEETING RELIABILITY GOALS

High system reliability is obtained by application of redundancy to assure that no single failure results in premature mission termination. The failure mode and effect analysis (FMEA) has proved to be the most effective tool in identifying potential problem areas. It is used to determine redundancy allocation for elimination of single failure points and to establish requirements for fault detection and isolation of the system, including redundant paths. An integrated parts selection, test, and supplier control program assures that equipment/system reliability requirements are achieved.

1.6.14 LOW COST AVIONICS SYSTEM

A number of problems exist in the design and development of a low cost avionics system; the more difficult problems include:

- Software development
- Onboard Checkout (OBC) and redundancy management
- Fly-by-wire using multiplexed data bus digital flight control system

Although these problems do not require technological breakthroughs, they are complex, costly and require innovative solutions to meet weight and performance requirements.

The orbiter software problem is that over a million words of software development are required to meet the orbiter operational and development testing requirements. To handle this problem the approach is as follows:

- Establish an intra-program element control board to assure compatibility and maximum exploitation of commonality

- Design computer hardware to minimize software requirements by (a) oversizing capacity and computational capabilities, (b) use of floating point hardware, (c) avoiding externally-demanded interrupts and (d) avoiding multiprocessor software
- Design computer software for use of higher level languages
- Select computer manufacturer with a large base of available assemblers, compilers, diagnostics, linkage editors and subroutines

Current OBC capability on a military or commercial aircraft yields an 80% detection and isolation capability at a 30% false alarm rate. The problem is that the orbiter autonomous requirements are for a 95% detection and isolation capability at a 10% false alarm rate. The orbiter problem is further compounded by the need to meet reconfiguration rates as fast as 20 milliseconds. The approach to resolve this problem is to:

- Supplement built-in test and self-test features with intra-element comparison and voting circuits
- Use a systematic approach in the definition of requirements and interfaces for inclusion in procurement specifications
- Use an evolutionary process to achieve near autonomous operation after subsystems and vehicle are certified

The flight control system (FCS) combines a number of innovative features such as (a) quadruply redundant, automatically reconfigurable computers, (b) fly-by-wire and (c) the data bus concept. To minimize risk in the development program, the following approach is taken:

- Systems are quadruply redundant with minimum multi-threading
- Flight control functions are isolated from other functions to minimize the probability of interactive failures
- The data bus is designed for a message error rate less than one part in 10^{25}

Other less significant avionics problems include solid state power management, high temperature antennas, heavy reliance on multipurpose CRT displays and data entry keyboards, and the availability of the NASA Tracking and Data Relay Satellite.

1.6.15 EXTERNAL TANK ENGINEERING DEVELOPMENT ISSUES

Since a number of the differences between an external tank orbiter (H-33) and an internal tank orbiter (G-32) are associated with the external tanks themselves, all of the external tank engineering development issues are covered in a separate section of this Engineering and Development Plan. There are no missing technology (critical technical risk) items among the issues, all of which are considered to fall in the category of difficult, but straightforward, engineering development items as follows:

- Dynamic effects of external tanks during launch and boost
- Tank fracture control, proof test, and strength tests
- Tank disconnects: avoiding GH_2 leaks and heat leaks
- Effects of ground hold environments (sun, wind, rain)
- Tank venting in orbit
- Tank separation and ejection without recontact
- Tank consumability and dispersions during reentry
- Tank depressurization, separation and ejection during abort modes

1.7 COMMONALITY

An important consideration in the detailed definition of the space shuttle system is the potential reduction of overall program costs through implementation of commonality. Commonality refers to those items that can be developed, processed, and/or performed in a common manner. It includes not only hardware, materials, procedures/techniques, and software common to the orbiter, booster, or associated ground systems, but also encompasses facilities, procedures, and services (training, logistics, etc.) that apply to common hardware items.

Achievement of the full cost saving potential resulting from implementing the NASA commonality program requires that common usage candidates be identified early in the program. Accordingly, tables of equipment, procedures/techniques and software commonality candidates have been developed and are included in the appropriate systems and subsystem sections of this plan. No attempt has been made to assign commonality and/or development responsibility.

Commonality Management is described in the space shuttle Orbiter Program Management Plan.

1.8 CONFIGURATION AND CHANGE CONTROL

1.8.1 INTRODUCTION

This subsection summarizes the management techniques that will be applied to the engineering aspects of orbiter configuration and change control. Subsection 3.6 of the program management plan describes the overall configuration management plan.

Engineering's task in this area is to provide design data to define the orbiter and subsequently provide change documentation to support both change control and actual implementation of changes.

Off-site changes will be formally endorsed by Engineering.

An action item and drawing status system will be established.

1.8.2 PRINCIPAL ACTIVITIES

Figure 1.8-1 shows the principal paths to be followed within engineering to assure that documentation will be released on schedule with the content rigorously controlled. Figure 1.8-2 shows the handling, within engineering, of change control documentation. Each principal activity is described in the following paragraphs and the paragraph number is shown on the diagram.

1.8.2.1 Inputs

1.8.2.1.1 Engineering Management System

Since adequate control of resources requires thorough management of the design effort, a detailed manpower, cost, and schedule system is planned for the orbiter program. To accomplish this objective, engineering will use a computerized system to monitor and control design and development of the orbiter. This system, identified as the Engineering Management System (EMS), will provide management with visibility into progress of the design and development phase. The EMS is an automated PERT/cost system which uses IBM's Project Management System (PMS) as a base. It provides an efficient method of

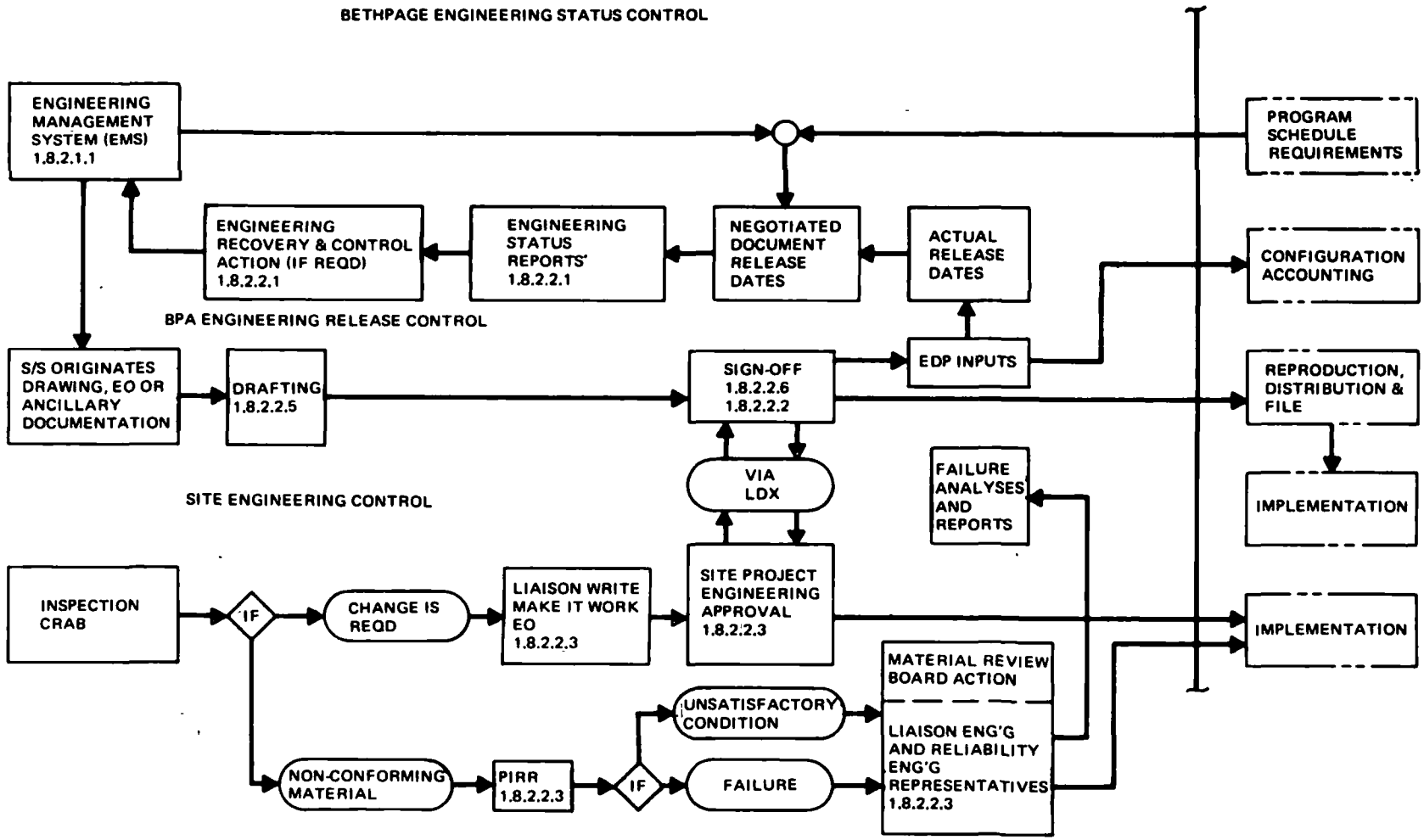

Fig. 1.8-1 Engineering Management Release Status & Site Control

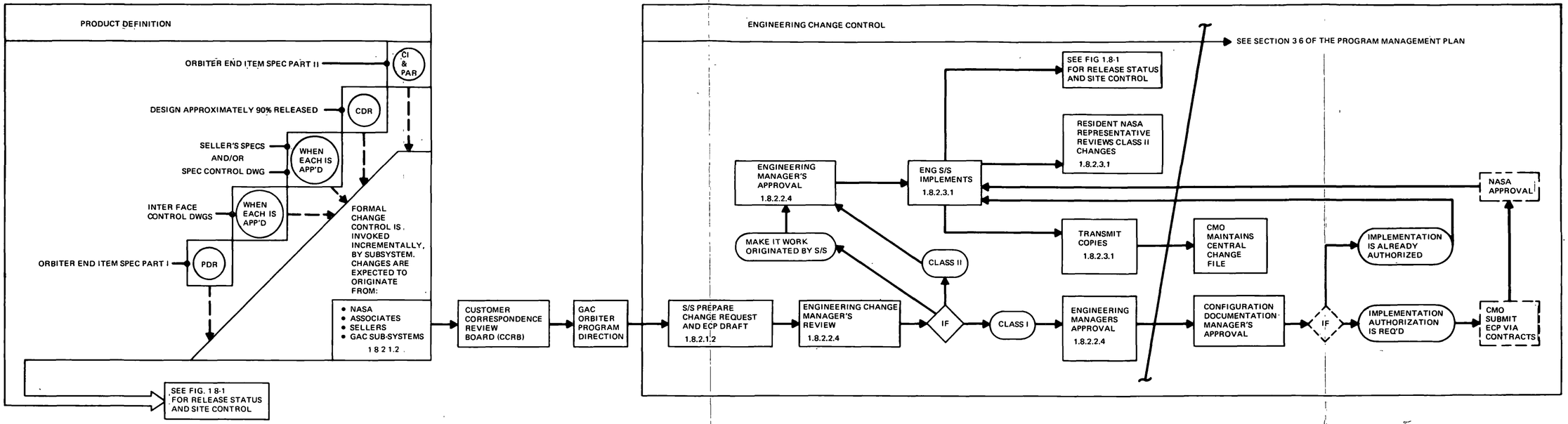

Fig. 1.8-2 Engineering Change Control Effort Flow Diagram

computerized assistance for cost and schedule control when used in conjunction with the engineering master schedule. This allows monitoring of significant milestones to determine that the design effort is on schedule and that resources expenditures are within budget. Periodic status reports, together with graphic representations, will be computer generated and will permit evaluation of both progress and problem areas early in the program.

Using the elements of the work breakdown structure, engineering will develop a PERT network depicting interfacing activities, modularized by work package. The work packages, when joined together, form the total integrated engineering plan.

Each activity will be identified by task description, duration, discipline, schedule constraints and the estimated man-hours required to complete the task. This information is linked together to form a network which, when continuously updated, becomes a dynamic management tool. A typical network will consist of a series of interdependent engineering tasks which schedule the release of drawings to manufacturing. The plan is developed as follows: first, by determining the activities leading to the release of a drawing and second, by determining the manufacture need date for the drawing by (automatically) calculating back from a contractual date (e.g. first horizontal flight) using predetermined incremental flow times at the detailed part level for the various manufacturing and procurement aspects of each part on every drawing. This method allows engineering to determine the areas of conflict so that adjustments to the plan may be implemented.

Once the plan is established (i.e. no negative slack), manpower requirements are automatically determined by summarizing all the tasks by discipline over the duration of the program. The drawing release plan can then be updated and displayed in either graphic or tabular format. As tasks are completed, the system is statused with completion dates and actual expenditures, and the impact reflected in the periodic status reports. Critical paths are determined so that management attention can be directed to problem areas.

In summary, EMS will trace a continuous computerized chain of events from contract award, through all engineering, procurement and manufacturing operations to end item delivery and will provide schedule progress and resource control data through periodic status reports.

1.8.2.1.2 Origin of Changes

Change requests will be logged in by a Customer Correspondence Review Board (CCRB) and engineering action items will be assigned to each affected organizational element by the engineering representative on that board.

1.8.2.2 Activities

1.8.2.2.1 Recovery Control and Status Reports

When negative slack is reported, a specific recovery plan will be established through the integrated efforts of all affected departments, and computer inputs to EMS will be revised accordingly upon implementation of the recovery plan. Status reports will be generated by EMS.

1.8.2.2.2 Drawing Release and Control

A drawing release and control group will review, release and control all engineering drawings. This responsibility will include review and concurrence prior to release for manufacture, of all engineering drawings, associated documents and changes thereto.

See subsection 1.12 for additional information.

1.8.2.2.3 Site Engineering Control

To provide assurance that all changes made off-site are consistent with both technical and administrative requirements, an engineering project office representative with signoff authority will be stationed at each site where change activity is planned.

Engineering will also be represented on site by liaison engineers and reliability engineers. No change to items under direct Bethpage engineering design cognizance will be implemented without prior Bethpage engineering signatures, except those minor repairs authorized in the Minor Discrepancy Manual.

1.8.2.2.4 Coordination of Changes

A major consideration in engineering is to maintain an accurate "as engineered" configuration definition. This task was accomplished quite successfully on LM by using the Engineering Product Plan (EPP) to define the "as planned" configuration and the Engineering Release File (ERF) to define the actuals. Both of these programs provided source data

for the Configuration and Traceability (CAT) run. The orbiter system EMS incorporates the best features of not only our LM experience, but also our recent aircraft experience.

To provide rigorous technical control, it is planned that schematics will be firmed early and will be reviewed in conjunction with hardware change documentation so that hardware and schematic changes will be released concurrently.

1.8.2.2.5 Drafting

A drafting procedure will be prepared to control the documentation of the as-designed configuration of the orbiter and provide NASA with all documentation necessary for review, evaluation and support of the program goals and objectives. For computer controlled wiring see subsection 5.6.

1.8.2.2.6 Specification Deviations and Waivers

To provide an instrument to control and process limited or temporary departures from specified requirements, deviations and waivers will be processed in accordance with Grumman-prepared procedures based on MIL-STD-480 principles coupled with experience on past and present space and aircraft programs. See subsection 1.10 for additional specifications information.

1.8.2.3 Outputs

1.8.2.3.1 Engineering Change Release

Formal change control will be established incrementally, by subsystem. Once change control is initiated, no engineering releases will be made against a change request prior to approval of the change. Copies of those documents pertinent to the cost history of the change will be forwarded to the Configuration Management Office (CMO) for filing with the original of the approved change request.

1.9 SELLER REQUIREMENTS

Since a substantial portion of the orbiter will be subcontracted, an effective system for control of subcontractor (seller) activities is required during each stage of the program cycle. Grumman has, through past space and aircraft experience, developed a comprehensive corporate procedure for the identification and management of seller requirements. It encompasses the total scope of seller activity including:

- Definition of technical requirements
- Determination of documentation requirements
- Seller proposal preparation
- Seller selection and negotiation
- Purchase order execution
- Management and controls

The complete technical requirements are defined and controlled by means of a design control specification and/or specification control drawing for each buy. In addition to performance and design requirements, the specification provides requirements for identification and traceability, reliability, and testing. Both standard and unique requirements are covered. Provisions for design verification, qualification and acceptance tests are included as appropriate. Each specification is tailor-made to ensure efficient integration of seller hardware (or software) into the overall system.

Non-technical requirements are defined in an accompanying seller requirements (SR) document. The SR lists the hardware, software and services to be provided by the seller with the quantity and delivery schedule specified for each item. It also stipulates detailed instructions for the accomplishment of each item as well as the conditions of purchase including pass-down clauses from the prime contract.

The specification and its associated SR constitute the basis for invitation to quote (ITQ) packages sent to potential bidders. Responding seller proposals are evaluated from technical, management and cost viewpoints in accordance with the formal corporate procedure. Selection of a preferred bidder results in Grumman/seller negotiations in which engineering and other appropriate functional disciplines participate. Once the negotiation has been successfully completed, the negotiated documents are incorporated either by reference or direct inclusion into a formal purchase order. Subsequent changes are rigorously evaluated and controlled.

During the procurement cycle, engineering is continually aware of the seller's technical approach, progress, problems and accomplishments by virture of certain control criteria incorporated into each purchase order. This criteria includes:

- Criteria for periodic Grumman/seller informal working sessions
- Requirements for formal design reviews
- Requirements for formal documentation (seller change proposals, drawings, analysis, etc.) which will be submitted for Grumman's evaluation and subsequent approval or disapproval
- Tasks and responsibilities of resident Grumman engineers, when applicable
- Seller change control board and procedure

Successful techniques developed for procurement control on the Lunar Module and F-14 programs are adaptable to the shuttle to ensure that the management, cost and technical requirements for each purchase are totally identifiable and controllable at each stage of the procurement cycle from inception through final execution.

1.10 ENGINEERING SPECIFICATIONS AND STANDARDS

1.10.1 ENGINEERING SPECIFICATIONS AND SPECIFICATIONS RELEASE SCHEDULES

The specifications program provides technical program definition for control of:

- Material and equipment procurement
- Compatibility between vehicle and support equipment
- Interfaces with other program elements
- Use of materials and finishes
- Testing
- Manufacturing processes
- Compliance with contract requirements

To minimize cost, existing documentation and Grumman standardized specifications systems and procedures are used where possible. Management visibility is attained by a progression of documents starting at the systems level and terminating at the component level. Essential elements of the specifications program are shown in Fig. 1.10-1. All planned and actual specifications are listed on an up-to-date expanded version of this tree. Assignment of specification identification numbers are standardized. Status of each specification is tracked on a computerized index with emphasis on configuration control. The index is updated continuously and is published periodically and distributed to specification users. This is particularly important in the area of process and material specifications to provide manufacturing and quality assurance a central data source for applicability (usually by date) of the latest revisions and amendments. The schedule for specifications preparation is shown in Fig. 1.10-2 and 1.10-3.

The program is administered by an engineering specifications group covering both vehicle and support engineering. This group coordinates and prepares all specifications and works under the direction of the orbiter engineering business manager. Implementation

of the specifications program is through the use of an engineering specifications plan prepared specifically for this program. Technical information for specifications is furnished by engineering disciplines as required. All documents are thoroughly reviewed for:

- Participation by cognizant areas
- Technical accuracy
- Compatibility between vehicle and support equipment

The format and content of contract specifications for systems, subsystems, and other major items meets the requirements of the appropriate appendices of MIL-STD-490 and consists of either Part I or both Parts I and II as necessary. These specifications baseline the design and performance requirements of the orbiter and form the basis for design reviews. Based on experience on both space and aircraft programs, the use of addendum specifications is minimized since maintenance and use of such documents are cumbersome. Instead, independent specifications are used. Maintenance of these documents is by use of SCN's accompanied by replacement pages. Unless it is desired to redefine a baseline, revision of these documents is not necessary since updating automatically takes place as changes occur and pages are replaced. Revision description indices and ECP logs are used.

Design control specifications and the associated specification control drawings for both make and buy items are prepared in Grumman standard format but meet the intent and content requirements of MIL-STD-490. For maintenance and configuration control, an independent specification is used to define each configuration or black-box dash number. If the amount of change from one configuration to the next in the same family is not extensive, addendum-type specifications are used. The change cycle for such specifications is independent of the parent specification. All design control specifications are maintained through a system of amendments and revisions. For change control, amendments are nonaccumulative. Revisions are issued only when it is considered essential for clarity or for redefinition and contain revision description indices. All specifications contain ECP logs. Amendments and revisions are not used in such a fashion that they effect the interchangeability of the equipment.

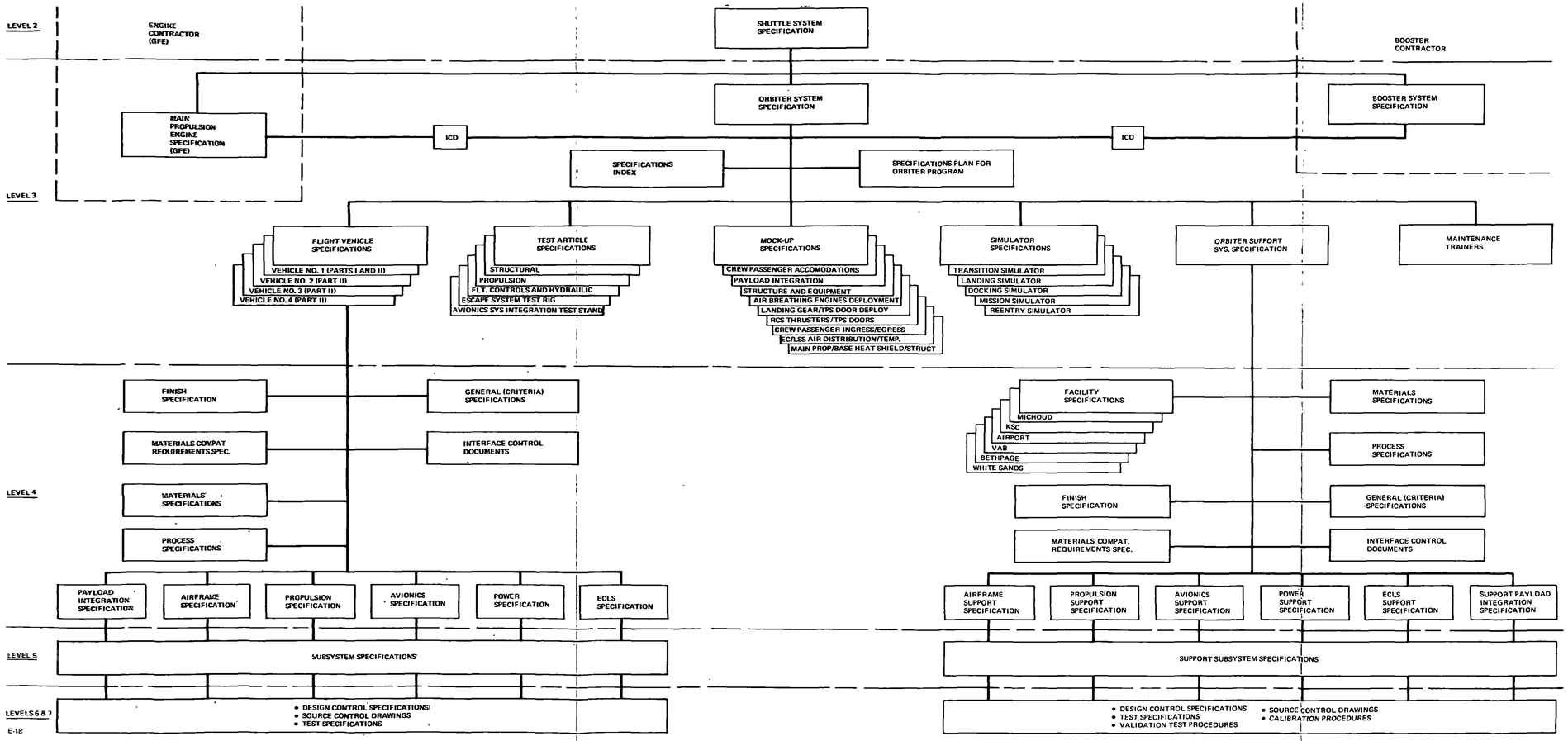

Fig. 1.10-1 Specification Tree

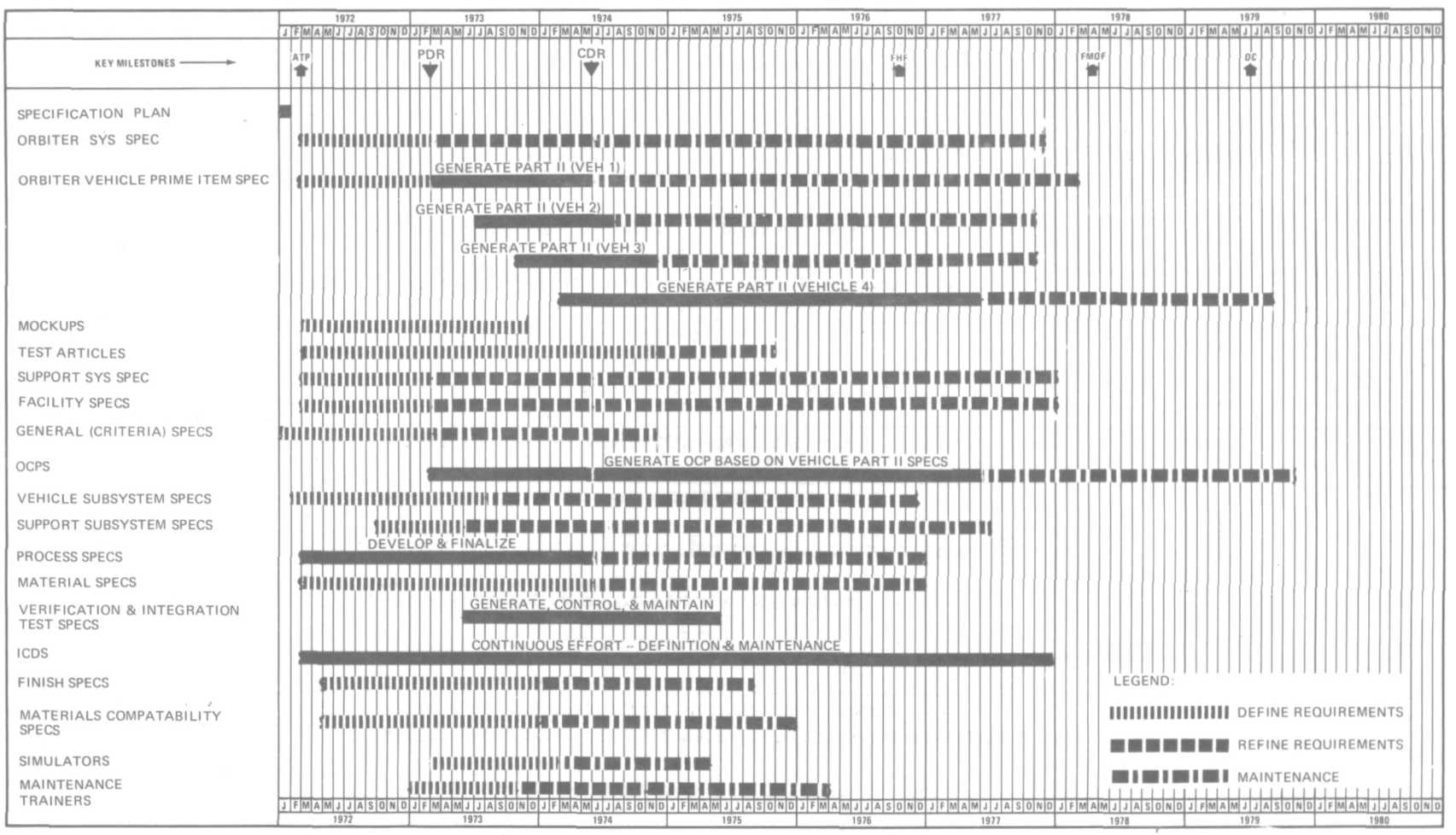

Fig. 1.10-2 Specification Release Schedule (Sheet 1 of 5)

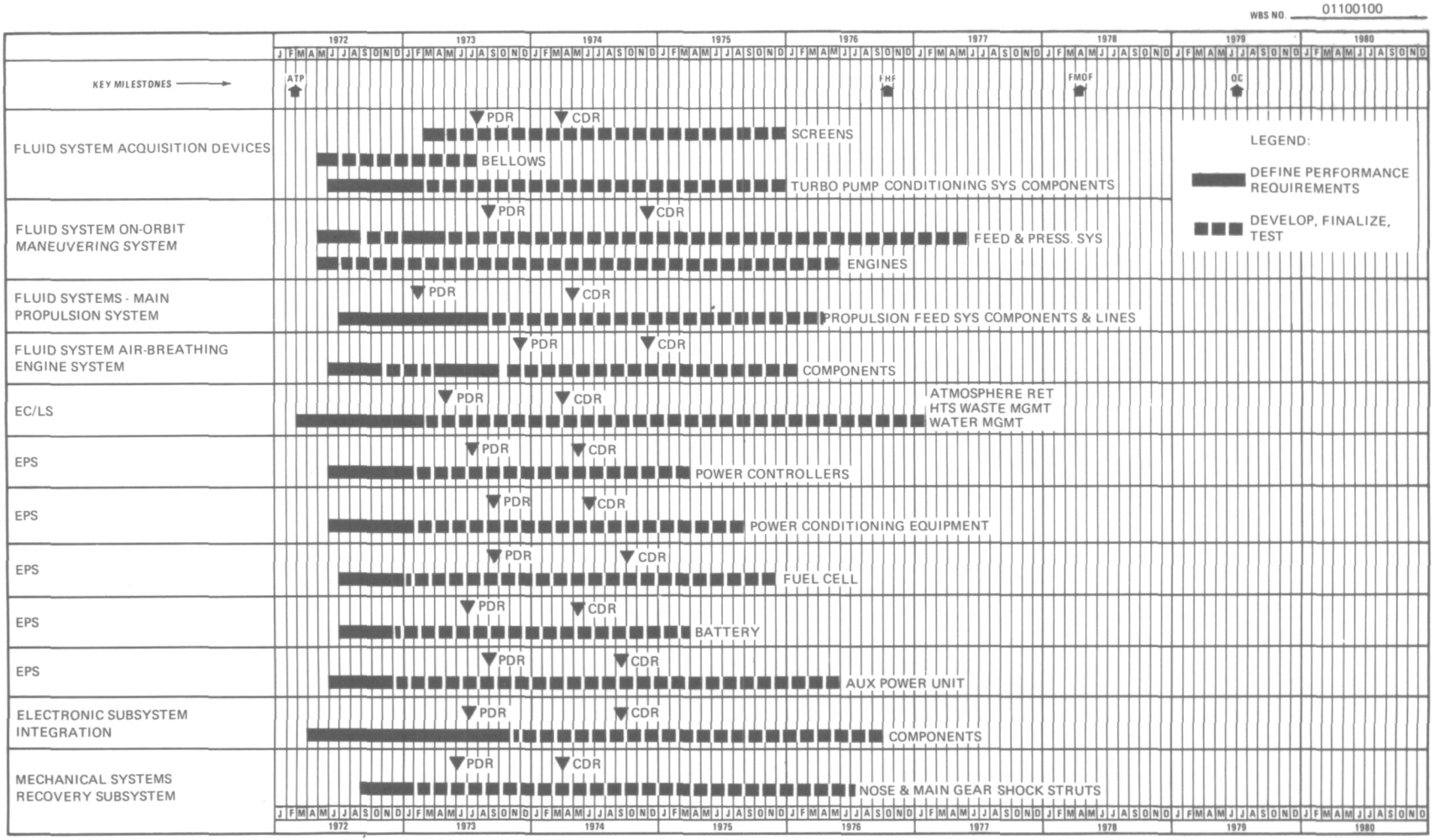

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Fig. 1.10-2 Specification Release Schedule (Sheet 2 of 5)

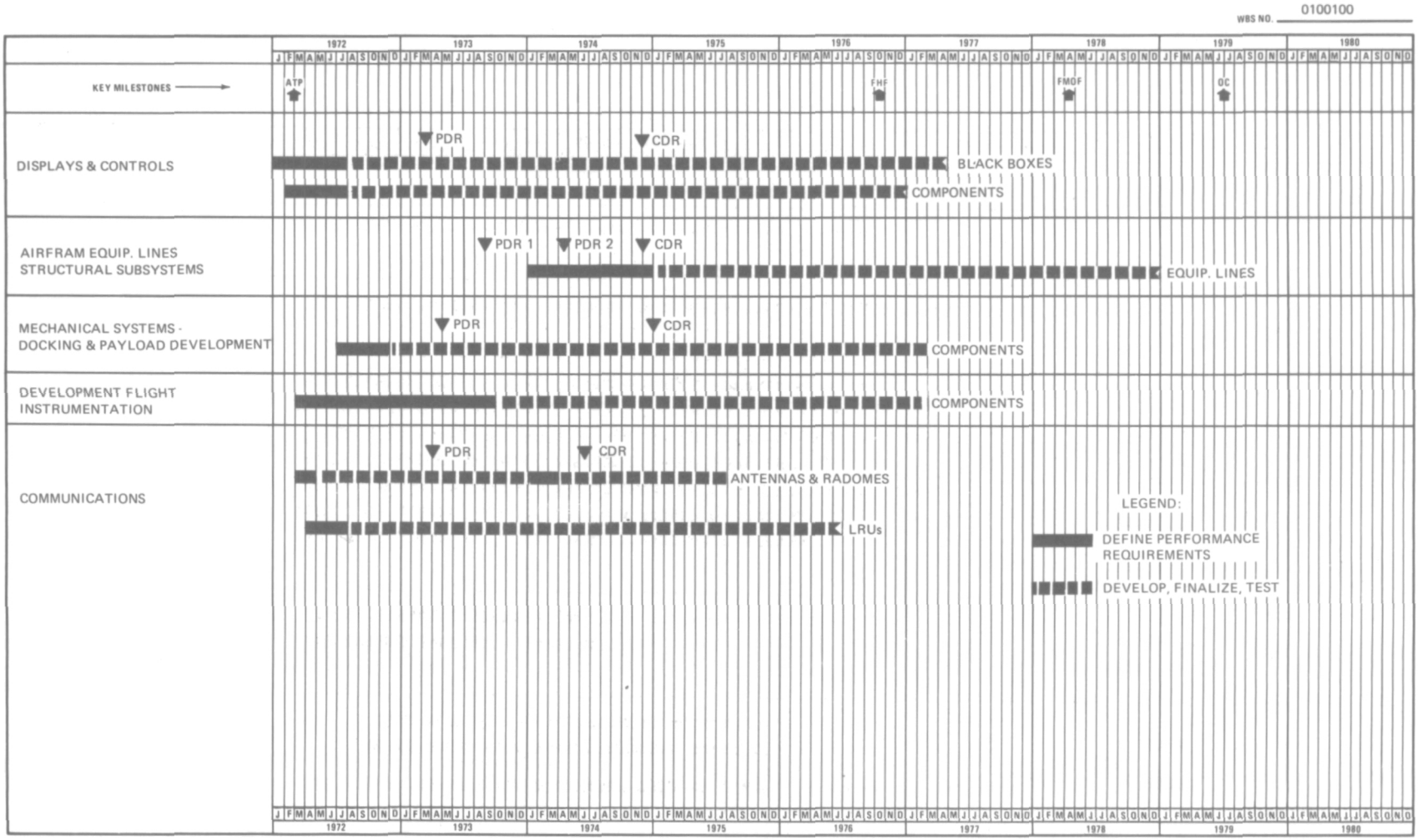

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Fig. 1.10-2 Specification Release Schedule (Sheet 3 of 5)

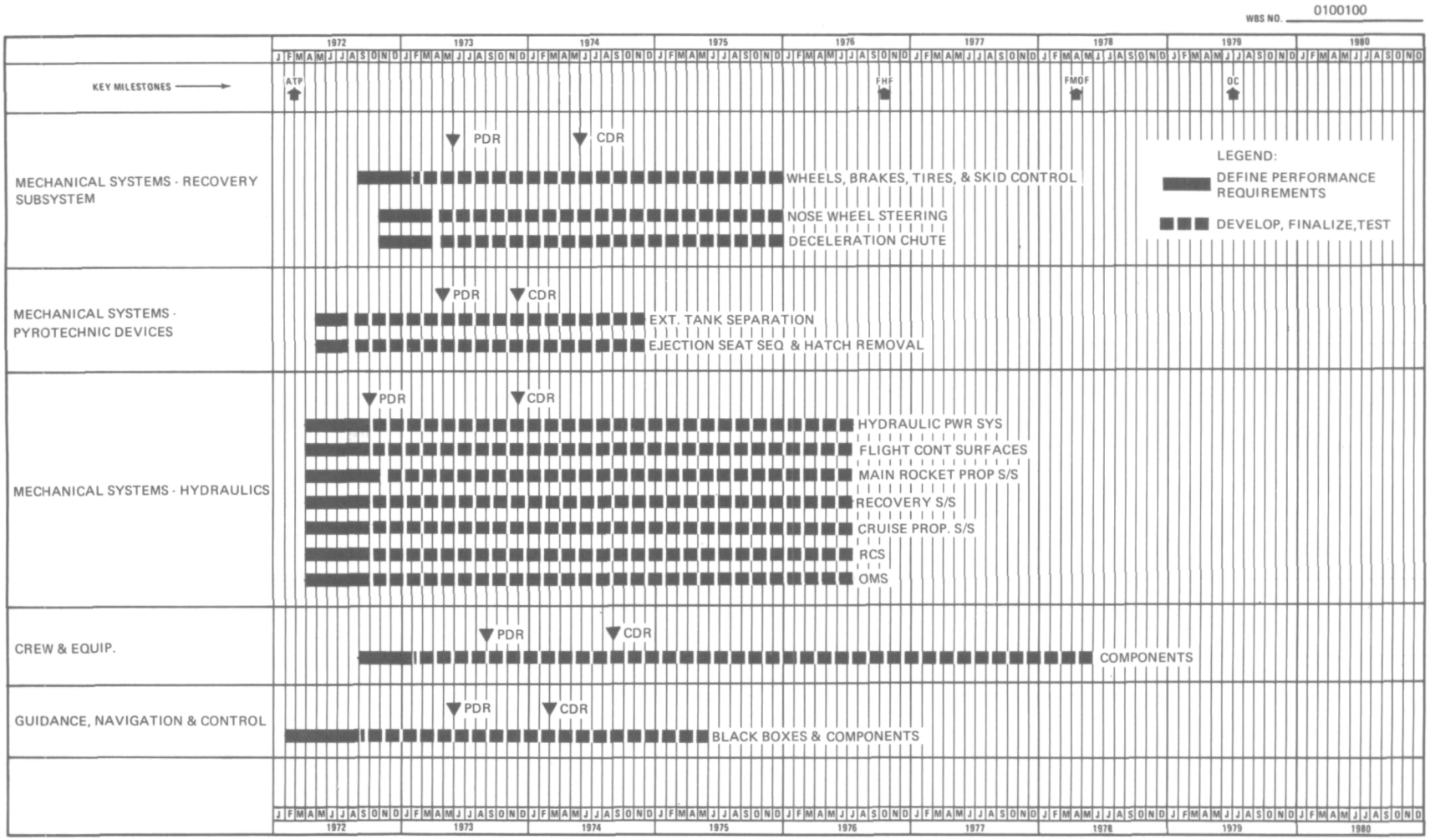

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Fig. 1.10-2 Specification Release Schedule (Sheet 4 of 5)

WBS NO. 01100100

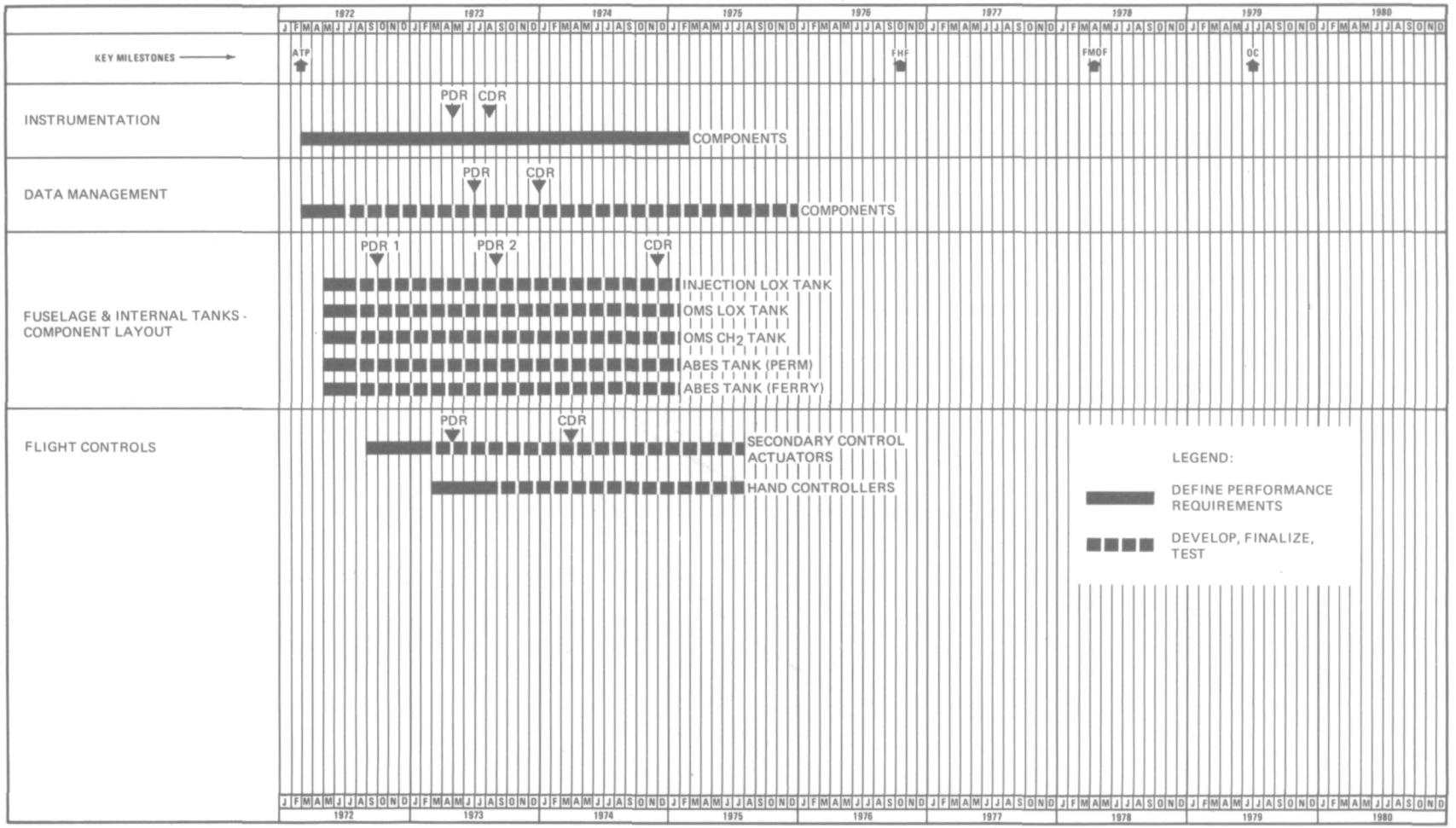

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Fig. 1.10-2 Specification Release Schedule (Sheet 5 of 5)

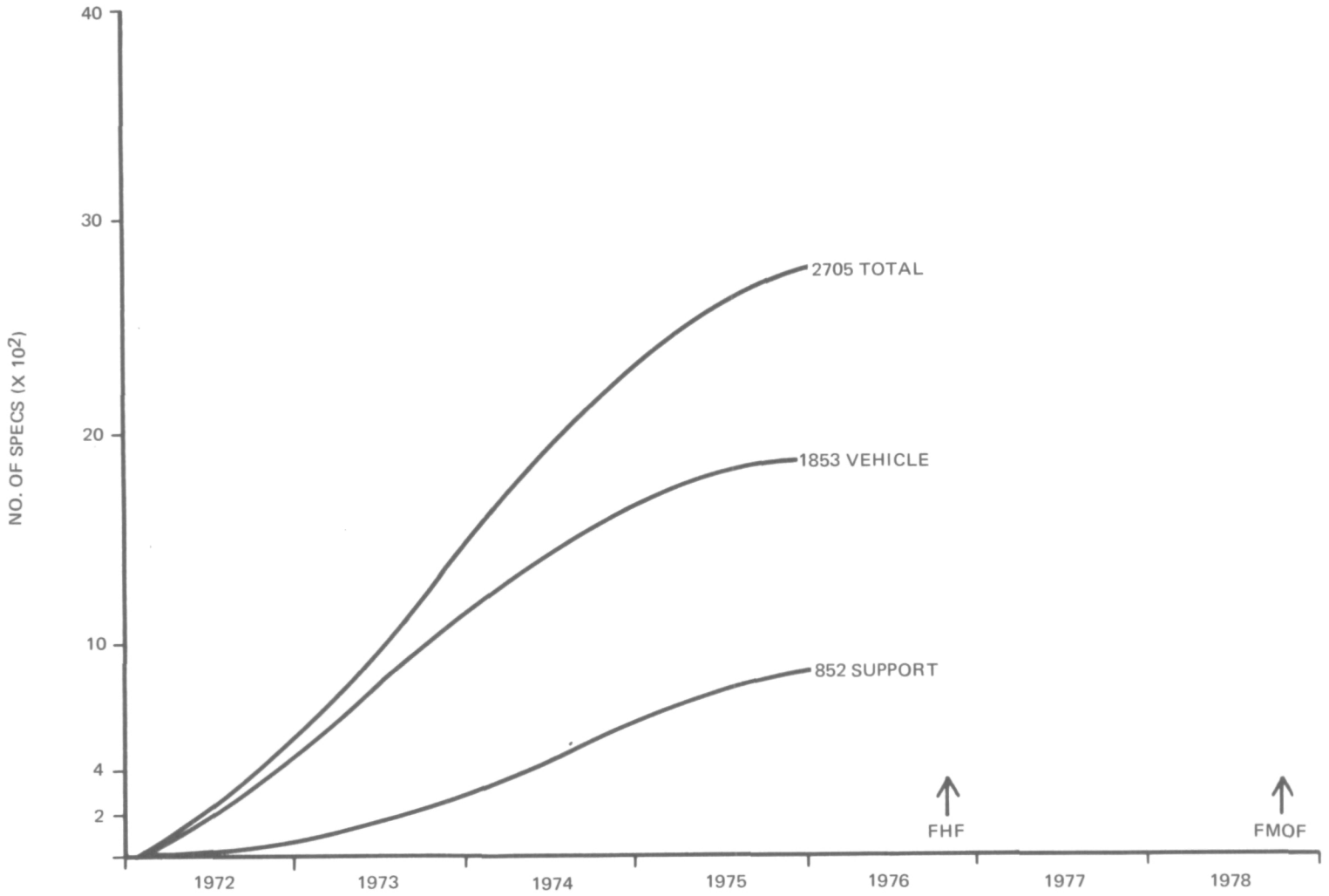

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Fig. 1.10-3 Estimated Spec Release Curve, Excluding Spec Control Drawings

Materials and process specifications are prepared in accordance with Grumman standard practice, but, both format and content of these specifications closely parallel the appropriate appendices of MIL-STD-490. As far as process specifications are concerned, the emphasis is on essential engineering control to assure an adequate end product without unnecessary restriction of manufacturing methodology. Maintenance for both types is by amendment and revision and, as in the case of equipment specifications, these instruments are not used in such a fashion that they affect the interchangeability of the material or process defined by the original specification.

Other specifications, such as test specifications, general specifications, and interface control specifications are prepared in accordance with Grumman standard practice with no particular connection with MIL-STD-490. Test specifications for acceptance, qualification, and integration or verification, meet the intent of MIL-T-18303. General specifications and interface control documents are in a format consistent with good engineering practice. Except for interface control documents, which are maintained through a system of change requests and interface revision notices, these specifications are maintained by use of amendments and revisions similar to those used for design control specifications.

1.10.2 ENGINEERING STANDARDS PROGRAM

The engineering standards program provides a management tool to minimize the range of parts, materials, processes and finishes in order to effect economies in procurement, tooling, and manufacture and to enhance the effective use of materials. The program also assures control of identification and procurement of seller parts and materials.

To minimize costs, existing parts and materials are selected in accordance with the principles of MIL-STD-143A and NPC 250-1. Items are selected from standards where they exist, but in every case, must be technically suitable for their application. Such factors as function, environment, reliability, strength, safety, and interchangeability must satisfy the design requirements.

In the parts, materials, processes and finishes areas, the program encompasses current practices of the company. A major standardization tool is the Grumman parts list (GPL). This listing is a carefully selected list of items managed by engineering standards using the design knowledge and experience of areas such as mechanical design, electrical/electronic design, materials and product support. Other Grumman documents which

contribute to parts and materials standardization are: The Military Standards Manual, Standard Parts and Procedures Manual, Selected Catalog Parts Manual and the Substitution and Interchangeability List.

Identification of all seller parts and materials not already identifiable by military, industry or company standards, are assigned Grumman identification numbers in order to control sellers and to assure quality and repeatibility of parts selected.

To assure the selection and control of parts and materials and to minimize variety, the Grumman standard documents noted above are also to be made applicable to associate contractors.

1.11 DRAWINGS AND DRAWING RELEASE SCHEDULES

1.11.1 INTRODUCTION

All activities pertaining to drawing preparation, release, control and submittal to NASA are monitored by the drafting services section of product engineering. This section is comprised of a drafting group and a drawing release and control group, both of which function as an integral part of the engineering disciplines established for the orbiter program. Drafting services groups will initiate and maintain an objective dialogue with all engineering sections, sellers, associate contractors and NASA, relative to assuring compliance with NASA drawing requirements.

The drafting group prepares and maintains all vehicle and product support drawings. They also service engineering with personnel skills as necessary to support specific drafting tasks; compiles manpower, schedule and performance data reflecting task and time relationships; maintains quality control on all drawings, EO's and related documentation; assures compliance with applicable drafting procedures and requirements; and verifies the exclusive use of approved standards and specifications.

The drawing release and control group reviews, releases, and approves, prior to issue for manufacture, all orbiter engineering drawings, associated documents and revisions thereto. This group is also responsible for review, release and control of price information requests and advance material notices; recording the status of released drawings; assignment of part numbers, EO numbers and drawing change letters; controlling engineering drawing baseline for first article configuration review; and processing engineering data in EDP format to ensure positive control and visibility of program parameters and requirements.

1.11.2 SCHEDULE

The projected drawing release requirements are shown graphically in Fig. 1.11-1.

1.11.3 DRAWING PREPARATION

Grumman drawing and document formats will be used. Preliminary engineering drawings are prepared in the form of layouts, using Grumman commerical drawing

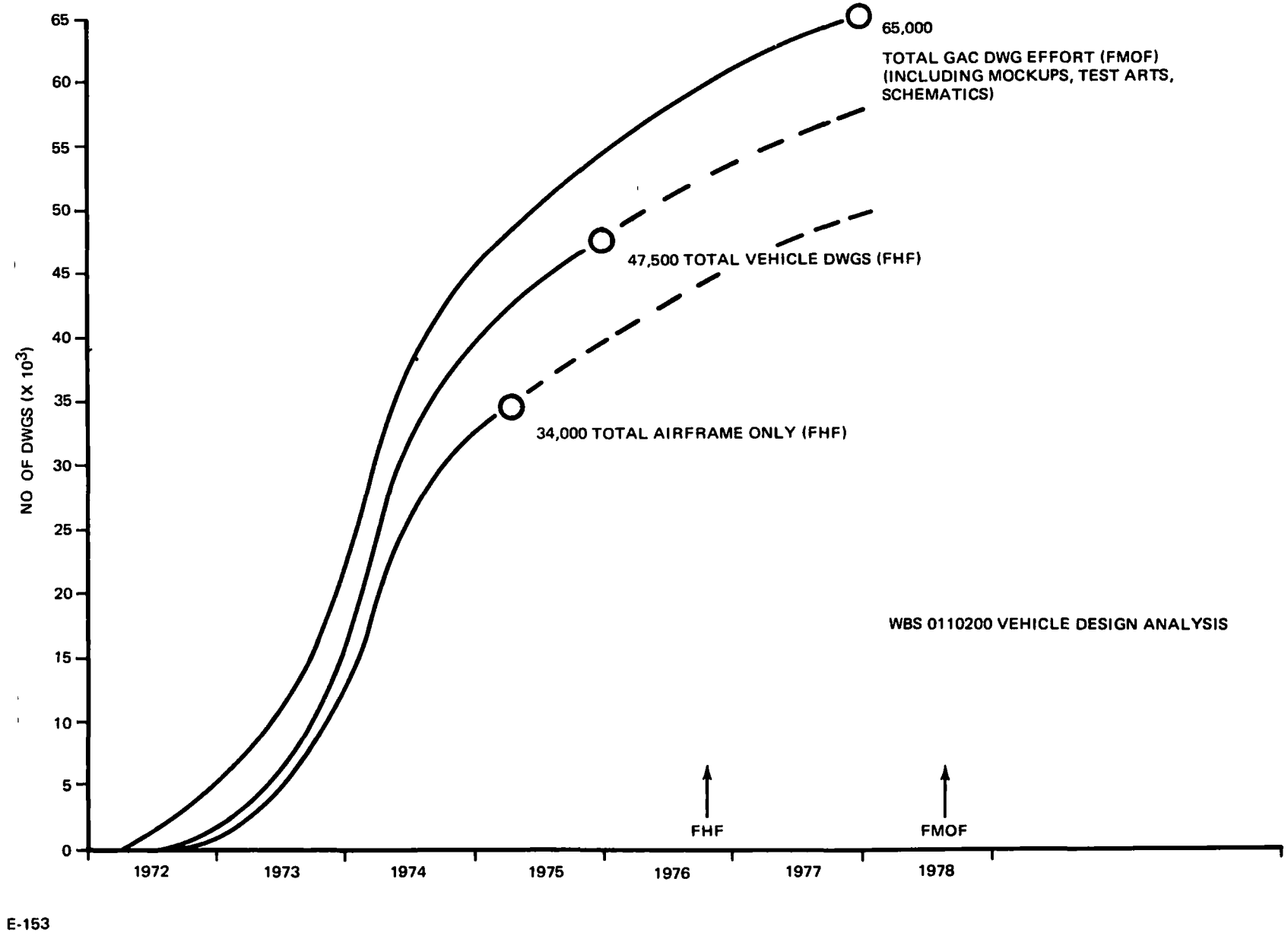
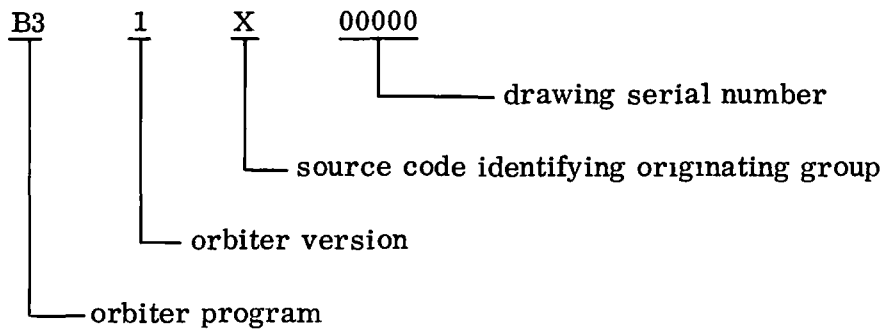


Fig. 1.11-1 Estimated Dwg Release Curve Excluding Vendor Drawings

practices. These drawings will delineate essential information needed for a technical evaluation of the proposed design. Final engineering drawings produced as a result of the contract effort will be delineated in general compliance with MIL-D-1000, engineering drawing requirements. Mandatory deviations to MIL-D-1000 are to be provided to NASA for review and concurrence prior to initiation of a drawing program.

1.11.4 DRAWING IDENTIFICATION

All Grumman prepared orbiter drawings are uniquely identified by a four element drawing number composed as follows:



All part numbers are composed of the drawing number on which the item is detailed and a dash number suffix. Under no condition will a part number exceed 15 characters. When items with Military or NASA assigned numbers exceeding 15 characters are required for use, a Grumman part number is assigned for use in lieu of the Military/NASA number.

1.11.5 INTERCHANGEABILITY AND REPLACEABILITY MARKING

Engineering drawings for component parts furnished to the NASA are marked to indicate the approved interchangeability or replaceability status. Military specification MIL-I-8500 is used for determination of parts requiring such marking.

New part numbers are assigned to identify parts which change status (i.e., configuration is improved to a higher degree of replaceability; or from replaceable to interchangeable).

1.11.6 CHANGE CONTROL

Engineering change control systems are discussed in subsection 1.8.

1.11.7 MICROFILM

Commerical quality Type I Class I silver halide microfilm in general accordance with Chapter 2 of NHB 1440.4A, will be prepared for all deliverable final drawings and associated documents. Mandatory deviations to NHB 1440.4A will be provided to NASA for review and concurrence prior to initiation of microfilm activities.

1.11.8 APERTURE CARDS

When contractually specified, microfilm will be mounted into Type I Class 2 aperture cards in accordance with Chapter 3 of NHB 1440.4A. NASA Forms 1273, 1274 and 1280, punched in accordance with Chapter 4 of NHB 1440.4A will be used.

Type II Class I copy cards in accordance with Chapter 5 of NHB 1440.4A, containing reproductions from Type I Class I microfilm, will be provided when required by contract. NASA will advise the contractor of the copy card style (A or B) to be used.

1.11.9 UNDIMENSIONED DRAWINGS

Where undimensioned drawings are prepared, reduced size positive and/or negative photographic reproducible copies on stable material are furnished to NASA, in addition to microfilm. These copies are prepared in accordance with MIL-D-8510B. Reproducibles of printed wiring drawings will not be furnished.

1.11.10 PRINTS AND REPRODUCIBLES

When prints and reproducibles are required to be furnished, MIL-D-5480D Type I Class I and Class II copies of documents and Type II Class I and Class II copies of drawings will be provided. Commercial legibility, contrast and reproducibility standards will be applied in lieu of comparable MIL-D-5480D requirements.

1.11.11 VENDOR DATA

The contractor has included the requirements of this subsection in all contracts with vendors. These requirements, however, are not applicable to vendor data considered of a proprietary nature. When vendor data is unobtainable due to excessive costs, the contractor will advise the NASA contracting officer or his representative to seek guidance.

1.12 SOFTWARE DEVELOPMENT PLAN

This subsection of the Engineering and Development Plan describes the requirements of computer software developments. The plan outlined will serve as a basis around which software concepts will evolve during the Phase C/D implementation.

The total orbiter software outlined in Fig. 1.12-1 is described to the level required to illustrate the respective roles in the overall development plan. Whenever practical, software will be used in place of hardware to more readily make system changes and to permit redesign in a more cost-effective manner.

Software specification conformance will be satisfied at several levels in the development process. Figure 1.12-2 outlines the procedural event sequences involved in the software development process. The levels of development shown will exist for all software, the degree or extent of development within these levels will be as specified in the individual design specifications generated during the ROS Program.

1.12.1 SOFTWARE DEVELOPMENT PLAN AND SCHEDULE

To ensure the success of any major development activity, it is necessary to provide control to management. The basic steps in the software development cycle are: requirements definition, system formulation and design, implementation, and testing.

The ROS software development schedule, Fig. 1.12-3, indicates program milestones in conjunction with the software event elements outlined in Fig. 1.12-2.

The project event diagram is typical of that required for large elements of the ROS program. The blocks on the diagram represent major events in the software development process. The labels within the boxes describe the functions to be performed with the items listed immediately to the right of each event box describing the expected end products or outputs of that event.

A brief description of the activities outlined in Fig. 1.12-2 follows:

1.12.1.1 Project Planning Phase

Based on system definition design goals and end-items, the software project enters the planning phase. The efforts associated with this event are concerned with developing work statements with accompanying milestones to meet end-item requirements. Project schedules, staffing, and work breakdown organization are then planned in detail.

1.12.1.2 Preliminary System Requirements

This initial event is the responsibility of the system engineering groups, the purpose being to describe the requirements of the end-item software system elements and their environments on a functional level. It is anticipated that software design personnel are used in supporting roles for this event.

1.12.1.3 System Engineering Preliminary Requirements Review (PRR)

At the end of the preliminary system requirements phase it is necessary to conduct a formal review (PRR). The purpose of this review is to confirm the overall software requirements.

1.12.1.4 Preliminary Software Design

The basic software system is designed based on the results of the PRR. A preliminary structure for an operating system is defined and hardware/software trades are made. The application programs are structured to the level of gross modules. Preliminary sizing and timing estimates are made.

The preliminary design activity concerns itself with software-oriented tradeoffs on computer architecture. Among them are:

- Floating point and double precision hardware requirements
- Interrupt structure and program control over interrupt priorities
- Suitability of computer and GSE for program verification activities
- Adaptability of object computer to specifics of application requirements via micro-programmed instructions

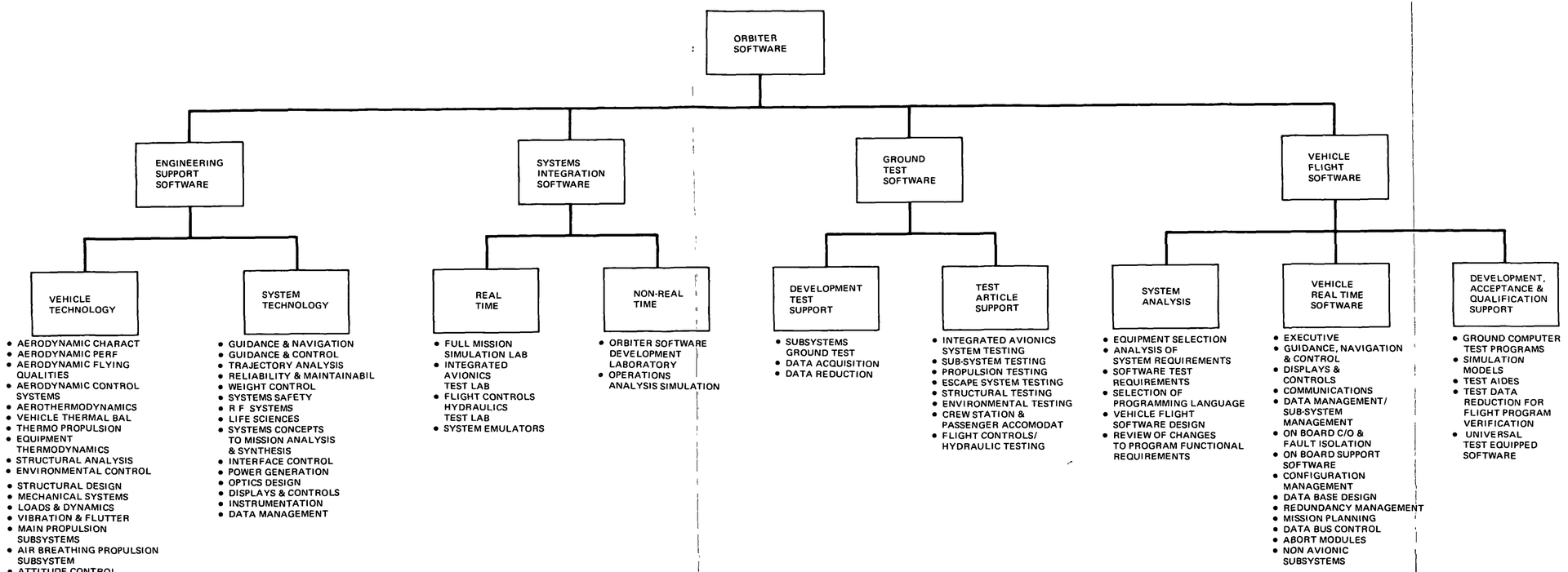


Fig. 1.12-1 Orbiter Software Configuration Tree

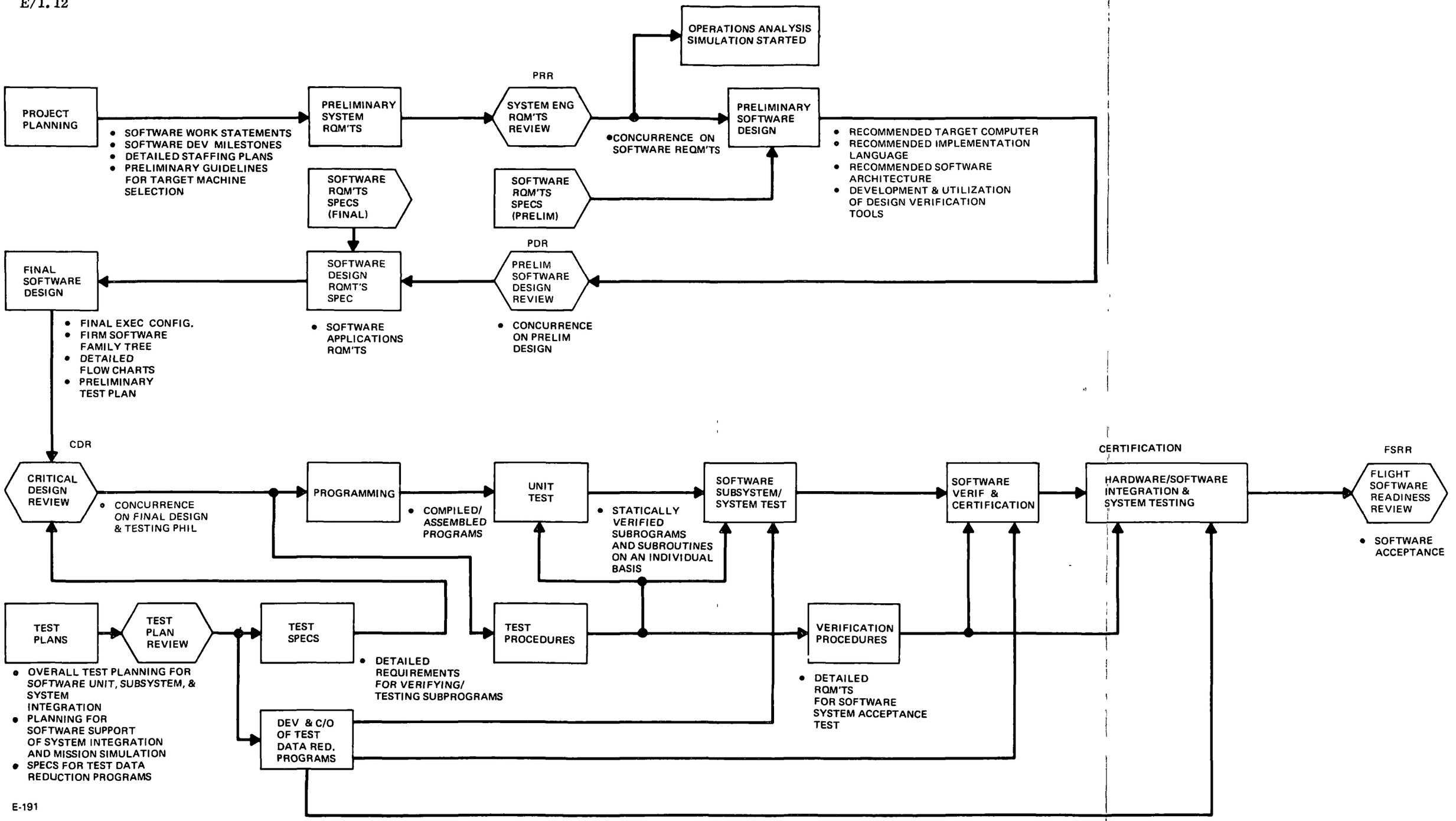


Fig. 1.12-2 ROS Software Development Plan

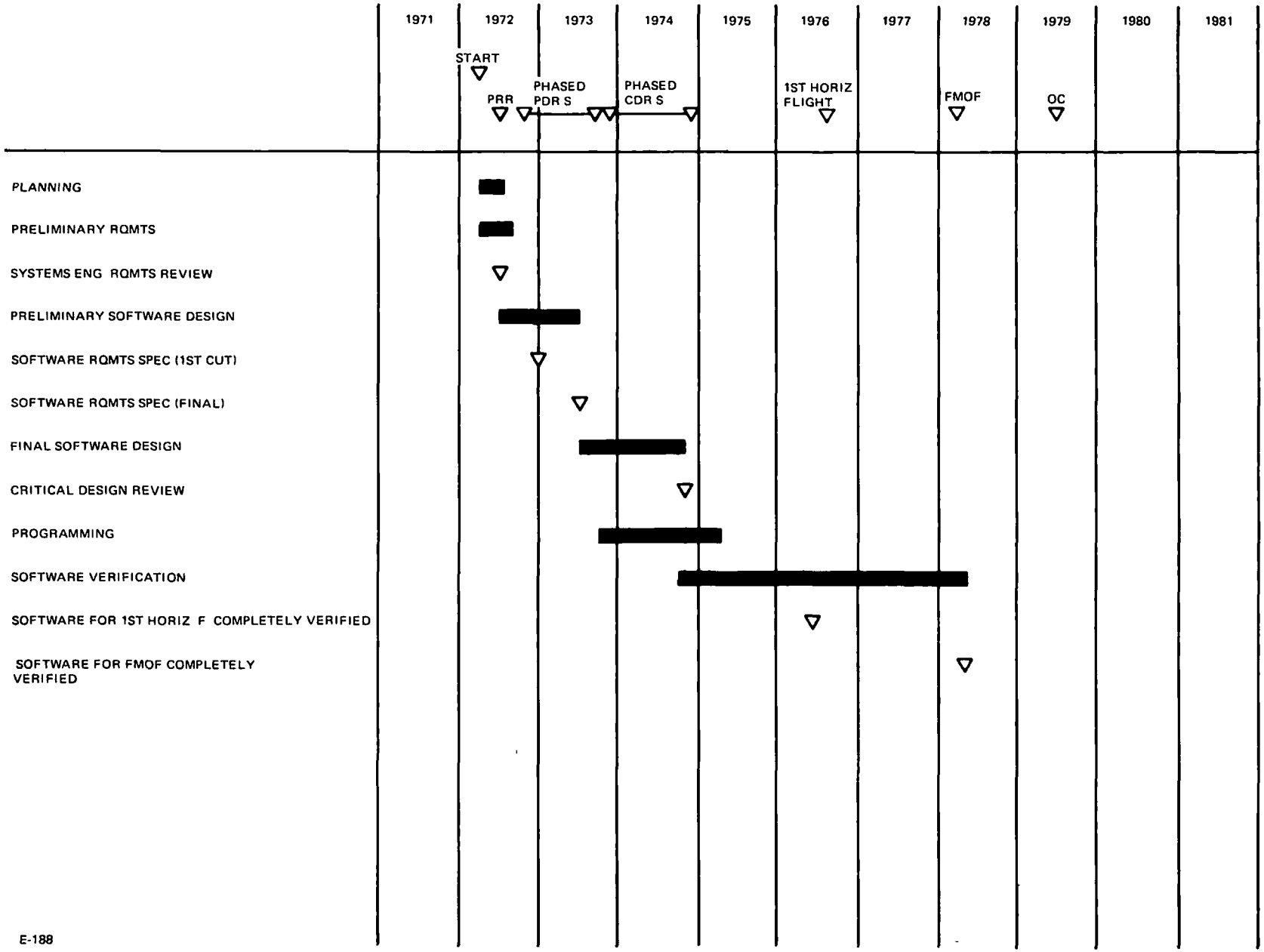
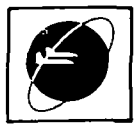


Fig. 1.12-3 Software Development Schedule



- Multiple clocks
- Adequacy of operational registers
- Memory expandability
- Sets of operational registers for hardware assistance in task switching

The results of these tradeoffs strongly influence ultimate computer selection decision.

In addition, the feasibility of applying a compiler language to the particular ROS program should be investigated. If an existing compiler is not readily available, the following courses of action can be pursued:

- Investigate modifications of existing compilers
- Investigate using higher level macro assemblers with formula conversion facilities for the ROS task

During the preliminary design activity, the following software architecture should be specified:

- Data base layout
- Executive architecture and timing
- Gross structure of the applications program modules and submodules
- Interrupt processing requirements
- Task selection philosophy
- I/O and data bus control techniques
- Program interface procedures and conventions

In developing software system architecture, emphasis should be placed on modularizing the executive and applications programs to as high a degree as possible to permit autonomous checkout. Commonality of functions should also influence the modular structuring of the ROS program so that the common function may be programmed to serve multiple application requirements. Commonality should not be pursued to the detriment of imposing awkward or unnatural requirements on software design modularity.

During the preliminary design activity, efforts should be made to compare, quantitatively, the various architecture and modular constructions as well as support the hardware/software tradeoffs. A tool such as a GPSS/SIMSCRIPT type model of the computing system should be employed to assess various software designs and verify compliance of the software design with the total system requirements. This type of modeling should be implemented in such a fashion that as the design parameters and the executive logic become firmly established in the implementation, the model may be updated to give current reports on the computing systems remaining growth potential. Use of such a tool to assess the growth potential of the orbiter computing system provides a strong measure of protection against the technical risks usually associated with development of large-scale computing systems.

1.12.1.5 Preliminary Software Design Review

This review is held at the end of the preliminary design period. The purpose of this review is to present and receive confirmation on the software design that has been developed to meet the system requirements.

1.12.1.6 Software Functional Requirements Specification

During this event in the software development process, the software system and subsystem design requirements should take place. Input to this event is the software external functional specification prepared by the systems engineering group. This specification contains all the details necessary for designing, programming and testing project software. Therefore, ROS software requirements specifications should contain the detailed equations, methods of solution, external program logic, and system modes of operation. The document represents the final software functional design and should be placed under configuration control at this point.

1.12.1.7 Software Design Activity

This event encompasses the detailed software design. The firm software family tree is developed, program and subprogram flow charts and specifications are generated. Firm timing and word budgets are assigned to the program elements. Subprogram and program interfaces are defined and preliminary test plans and documentation plans are generated.

1.12.1.8 Design Review

This design review, commonly referred to as the critical design review (CDR), involves the evaluation of compatibility with the total system functional requirements and final confirmation on the design to meet those requirements. The software testing philosophy is reviewed for compatibility with total system test philosophy.

Following successful completion of the design review, the software design specifications are placed under configuration control to provide control visibility of changes in the software design. The CDR is one of the major ROS software development events. Program implementation (coding and verification) can be initiated only after successful completion of the CDR.

1.12.1.9 Programming

In this event the code is written and compiled for the independent subprograms as per the programming specifications. The output of this phase are computer programs in compiled form on cards or tapes.

1.12.1.10 Unit Test

Following coding and compilation, the individual subprograms are tested in accordance with the requirements in the software test specifications.

1.12.1.11 Software Subsystem/System Test

This event is concerned with the integration of the subprograms into program modules. The test procedures are used to test the program modules on a function-by-function basis. Test data reduction programs are used to reduce and present the computer produced output from system and subsystem testing.

1.12.1.12 Software Verification and Certification Tests

In this event the ROS end-item software is tested as a stand-alone system using minimum ROS hardware.

1.12.1.13 Hardware/Software Integration

The end-item software is tested in a realistic environment with the project hardware operating as a full system. As in the case with subsystem/system test and software verification, test data reduction programs are used to acquire, reduce and present the results of the system integration testing.

1.12.1.14 Test Plans

Following design review, test plans are formulated based upon the software system defined test philosophy. The primary purpose is to detail test requirements for software unit tests and software system integration tests. Detailed specifications of test data reduction programs are developed for use in software testing. In the development of large, complex software systems, these programs plan an invaluable role in reducing and presenting test data for use in debugging the end-item program modules.

1.12.1.15 Test Plan Review

Following development of the test plans, a formal review is held with the software project and system engineering group to obtain concurrence on philosophy, content and schedule.

1.12.1.16 Development and Checkout of Test Data Reduction Program

This event is concerned with the development of programs to acquire, reduce and display the results of the end-item computer program testing. These programs are used for software subsystem/system test, software verification and hardware/software integration.

1.12.1.17 Test Specification

This event involves development and formalization of the detailed specifications for subprogram module testing.

1.12.1.18 Test Procedures

This is the development of detailed test procedures for function-by-function test of program elements.

1.12.1.19 Verification Procedures

This event relates to the development of detailed procedures for demonstrating the verification of the total software system.

By verifying and validating ROS software by checking the programs in a planned, controlled environment of program integration, the overall software system reliability is enhanced. All paths through the program code will be exercised and the results obtained will be compared with the theoretical values to verify compliance with the software functional specifications.

As a follow-on activity to hardware/software integration, three major activities are envisioned as requisites to first horizontal flight/first manned orbit flights:

- Nominal mission exercises to explore system characteristics/reactions with expected variable ranges
- Off-nominal mission exercises to explore system responses with variables out-of-range
- Malfunction mission exercises to explore system responses via redundancy paths

1.12.2 SOFTWARE CONTROL BOARD

The ROS software development team will play a major role in the Software Control Board. It is envisioned that this Board, and its standing subboards, such as the Software Flight Readiness Review Board will serve the following functions:

- Review changes to software functional requirements and approve or refer such changes to higher level integration boards
- Review contractor progress relative to
  - Detailed program design
  - Program implementation
  - Program test plans
  - Program checkout and integration
  - Program flight readiness
- Review memory space and real-time budget
- Review interface control documents (ICD's) between the board member software contractors
- Reconcile incompatibilities between software contractors
- Review and formalize software agreements
- Prepare items of disagreement for resolution by system integrator and/or NASA

- Review documentation by board members. Enforcing of documentation standards. Control function for software configuration control
- Report flight readiness of software elements. Report resolution of software discrepancy reports generated in software system testing

1.12.3 ORBITER SOFTWARE BASELINES

Figure 1.12-4 shows the hierarchial relationship of orbiter technical software. The major software elements of the orbiter are:

- Engineering support programming
- Vehicle flight software
- Ground test software
- System integration software

The following sections amplify each of the major software activities:

1.12.3.1 Engineering Support Programming

Engineering support software is concerned with the development, modification and application of analytical programming packages to support the engineering design activity. There are two logical areas that comprise the engineering support function:

- Vehicle design and development support programming
- Systems engineering support programming

Details of the various program modules employed in this functional area are described in other sections of this volume. Under vehicle programming support, computer programs will be used for aerodynamic analysis, airframe design, thermodynamic modeling and structural analysis. Grumman has developed an extensive set of library programs under project IDEAS to service the structural disciplines that can be applied to the ROS Program. In addition, Grumman-developed thermal analyzer and shell structure analysis programs have ROS application.

To support the system engineering function for ROS, several Grumman-developed software programs, with minimal modifications, can be directly applied. Some of these are for

electromagnetic compatibility analysis, radome and antenna design and analysis, power system load analysis, navigation, guidance and control analysis programs, and radar cross-section analyzers. The Grumman internal reliability/maintainability data system will be modified to support the ROS requirements.

1.12.3.2 Vehicle Flight Software

The ROS vehicle real-time programming group will address itself to the flight programs supporting the following major flight functions of the ROS system:

- Executive and data bus control
- Flight avionics subsystems control
- Flight non-avionics subsystems control
- Checkout and fault isolation (COFI) and reconfiguration control
- Flight controls systems

Vehicle flight software includes all software aboard the orbiter.

1.12.3.2.1 Rationale

The rationale used in the design of the optimal real-time system will provide the current configuration with the ability to adapt itself to any changes. This is necessary for a system as dynamic as the ROS.

1.12.3.2.2 Approach

The software system designed for the orbiter, will be based upon a modular design. The operational programs augmented by a modularized, bi-level executive control program, incorporates the capability for orderly change of the entire software system to meet changing operational requirements. This approach provides a continuing capability for software system change throughout the operational life of the Shuttle System. Current software system designs generally provide executive control programs tailored specifically for anticipated system functions. These designs provide flexibility in terms of the operational programs

but cannot be readily adapted to meet new system functional requirements. The executive will be developed to circumvent this problem by:

- Allowing for two levels of executive operation
- Modularizing the executive and the routines required to achieve flexibility

The level concept will facilitate the user change of the existing program structure. Modularization will allow for ease of program insertions, deletions, and will facilitate redesign of the existing system. An approach of this sort will allow for the orderly transition of the entire system and not just the functional program modules. Thus, provisions will be included, such that, the approach to the solution can be modified and not just the solution itself.

1.12.3.2.3 Scope

Design concepts for an overall approach to ROS flight software development.

1.12.3.2.4 Objectives

Develop executive control design for a processor that will manage resource allocation, task scheduling and data management for the following conditions:

- Real-time system normal operation
- Real-time system degraded mode - Priority step-down concept
- Split real/non-real time operation
- Mission and failure mode reconfiguring
- Astronaut manual override capability

Develop Executive Program:

- Timer
- Scheduler
- Keyboard response
- Real-time response
- Mission analyzer

- Software reconfigurer
- Hardware reconfigurer
- Self-modifier
- System modifier
- System initializer

Develop information display and recording (D&R) system design, which will allow for:

- Selected item(s) D&R by subject
- Selected item D&R by item name
- Selected subroutine callout by name or subject
- Select rates for real-time D&R
- Automatic D&R data compression by time or parameter selection (operator option)

Develop a utility design with three-fold concept:

- High-level control program to override executive in system sequencing, timing, priority, etc
- Low-level control programs tailored to encompass predictable programming requirements for changes or additions to existing program capabilities
- High-level compilers to cover unpredictable program needs

Develop operation program design concepts:

- Modular in design
- Relocatable
- Multi-functional (if applicable)

Develop OBC system design:

- Fault detection and warning notification (user notification)
- Fault isolation

- Mission protection
- Failure prediction and trending analysis (real/nonreal-time)
- Inventory bookkeeping and maintenance
- Maintenance and back-up modes
  - Module reconfiguration management (both H/W & S/W)
  - Spare availability
  - Functional circuit analysis down to line replaceable unit (LRU) level

1.12.3.2.5 Develop Universal Test Equipment Software

The universal test equipment (UTE), as described in paragraph 4.3.5.1 of the Operation Plan, will be used for the test and checkout of the avionics subsystems and system. It will be used in conjunction with the orbiter onboard checkout (OBC) to demonstrate and verify subsystem, system and vehicle readiness. In addition, it will be used to fault isolate and verify failed LRU's in the appropriate system/subsystem laboratories.

Presently a definition of what software will be required cannot be given. A detailed evaluation is required of UTE existing software to ensure compatibility with ROS program needs and objectives.

1.12.3.3 Ground Development Test Software

Ground development test software consists of all software to be used in support of ground tests and checkouts. The tests will be at the component, subsystem, and combined subsystem and vehicle levels. The only exception to this is the software required for the integrated system tests and simulation which will be placed in a separate category. These ground tests will be performed in a data reduction station (DRS) specifically built to handle all ROS data reduction and analysis. Use of the LM data reduction station (LDRS) with minor program and equipment modification is recommended to be used as a first step in development of an DRS to be used for the reduction and analysis of ROS test data. The following sections describe the primary software elements in ground test software.

1.12.3.3.1 Aerodynamics

Ground test software used for aerodynamic testing can be divided into two categories. The first is software used as data acquisition facilities such as those at the Grumman low speed wind tunnel. The second category will be analysis-type software to be used in reduction of data acquired at the wind tunnel facilities. In addition to software support, a ground station operation such as the DRS described above will be used to generate analog time histories, power spectral density (PSD) plots, and data conversion to engineering units.

1.12.3.3.2 Structural Analysis - Structural Test

Developmental test software required to support structural testing can be divided into two broad categories. The first is to provide software support for structural test acquisition systems such as the Grumman-developed "Myti Acq" system, structural test article. These systems in addition to functioning as an acquisition system, have real-time processing capabilities. The second category is that of post-test data reduction and analysis software. These categories of software support will be used for both component and structural article tests.

Test plans are discussed in subsection 10.3 of this document. Component testing will be conducted at Bethpage while the structural article will be tested at KSC. The structural acquisition system at KSC is currently being sized for 2000 measurements. Post-test reduction will, in most cases, be conducted at or near the test site.

Analysis typically consists of calculations for:

- Single strain gages - Engineering units
- Pressure gages - Engineering units
- Load and thermocouples - Engineering units
- Single strain rossette
- Maximum and minimum principle stress
- Maximum shear stress
- Angle of maximum shear

- Strain rossette for composite materials
- Stresses in principle laminate direction
- Percent load for more than one load cell
- Spanwise station difference in deflection rate

1.12.3.3.3 Propulsion Test

Development test software consists of programs for post-test analysis of engine firing data. The software will be similar to that used for cold flow and hot firing on LM, but additionally may require the capability to analyze certain onboard functions such as the propellant feed and pressurization, vehicle electric power, checkout and monitoring systems, and hydraulic power.

1.12.3.3.4 Crew Escape System

Crew escape system test software consist of the programs necessary to analyze the data from those tests. The test's location and objectives may be found in subsection 10.4 of the engineering development plan. The data typically consists of accelerometer measurements which may subsequently be played back on an analog display device or may be converted to engineering units. Additional data will be acquired via tracking cameras or theodolites. Data acquired at these facilities is used to calculate the trajectories of the dummies. It is not anticipated that any new software will be required for this testing effort.

1.12.3.3.5 Structural Dynamics Tests - Modal Vibration Survey

The software required for analysis of modal vibration survey data will consist of modifying an existing F-14 program to define the ROS geometries. The data acquisition and reduction system has been previously defined and used on the F-14 program and will remain as is for the Phase I, II, and III tests.

A major consideration is the location of the data reduction site. If it is necessary to perform the reduction at KSC, the current modal survey reduction program must be converted from a 360/75 program with batch interactive capability to a facility at KSC.

1.12.3.3.6 Thermal Protection System Tests (TPS)

The DVT and Qual Test program for the TPS will use the vibration, acoustic, temperature, and load test facilities located at Bethpage. A list of planned facility utilization may be found in subsection 3.4.8. Data reduction requirements are dependent upon test and will consist of analog processing such as PSD, ASD, and time history plots, engineering units listing and analysis. It is anticipated that the 1400 channel CSC digital acquisition system, or equivalent, will be utilized in conjunction with Thermal Vacuum Tests. Data reduction of Thermal Vacuum data typically consists of calculation of average temperatures, volume, delta pressures, and flow rates with plot or tabular outputs. Programs are currently available to perform these calculations and their adequacy will be evaluated against final engineering requirements.

In addition, one of the Static Load Test Facilities will be used for Temp/Load tests. Analysis software for loads data has been described in Structural Analysis ground support software. The remainder of the tests will require analog reduction only and can be placed in the category of miscellaneous.

It should be noted that the thermal protection system is a high risk area, and as such the extent of test software cannot be defined at this time.

1.12.3.3.7 Miscellaneous Testings

A series of environmental tests which may be either DVT or qualification tests will be conducted at the Bethpage facilities. These tests do not, in general, require software for analysis or on-line control/acquisition; however, they do, in many cases, have associated analog acquisition/recording systems. The data acquired on these systems required the use of the DRS to provide analog time history plots, power spectral density (PSD) plots, and amplitude spectral density (ASD) plots. Information as to the schedule of these tests is not available at this time.

1.12.3.4 System Integration Software

The ROS program development requires specialized system real-time/nonreal-time software to perform the following functions:

- Nonreal-time software to develop algorithms and control law formulation (subsection 2.19)

- Real-time software to functionally verify the above developments in a simulation environment, where applicable (FMSL, subsection 2.14)
- Nonreal-time interpretive simulation software to assist in flight program coding and debugging (OSDL)
- Real-time software to verify the hardware/software interface on a subsystem functional level (IATL, subsection 10.6)
- Real-time software to verify/certify the hardware/software interface and mission performance during end-to-end combined subsystem testing (FMITF, subsection 10.6)

The flight software development process form algorithm development to end product delivery is an iterative process of design, verification and modification as illustrated in Fig. 1.12-4. A certain amount of latitude was taken in developing this flow graph, by ignoring task overlapping, but it does serve to indicate the ordered iterative development process that flight program functions must follow. This repetitive, and in some cases redundant process, is necessary since the software represents a potential single point failure during its development cycle, in an otherwise redundant system.

The following integrated system test and simulation facilities are described in subsections 2.14 and 10.6:

- Motion base simulator (Phase I)
- Fixed-base simulator (Phase I)
- Full Mission Simulation Laboratory (FMSL)
- Integrated Avionics Test Laboratory (IATL)
- Flight Controls Hydraulic Test Laboratory (FCHTL)
- Full Mission Integrated Test Facility (FMITF)

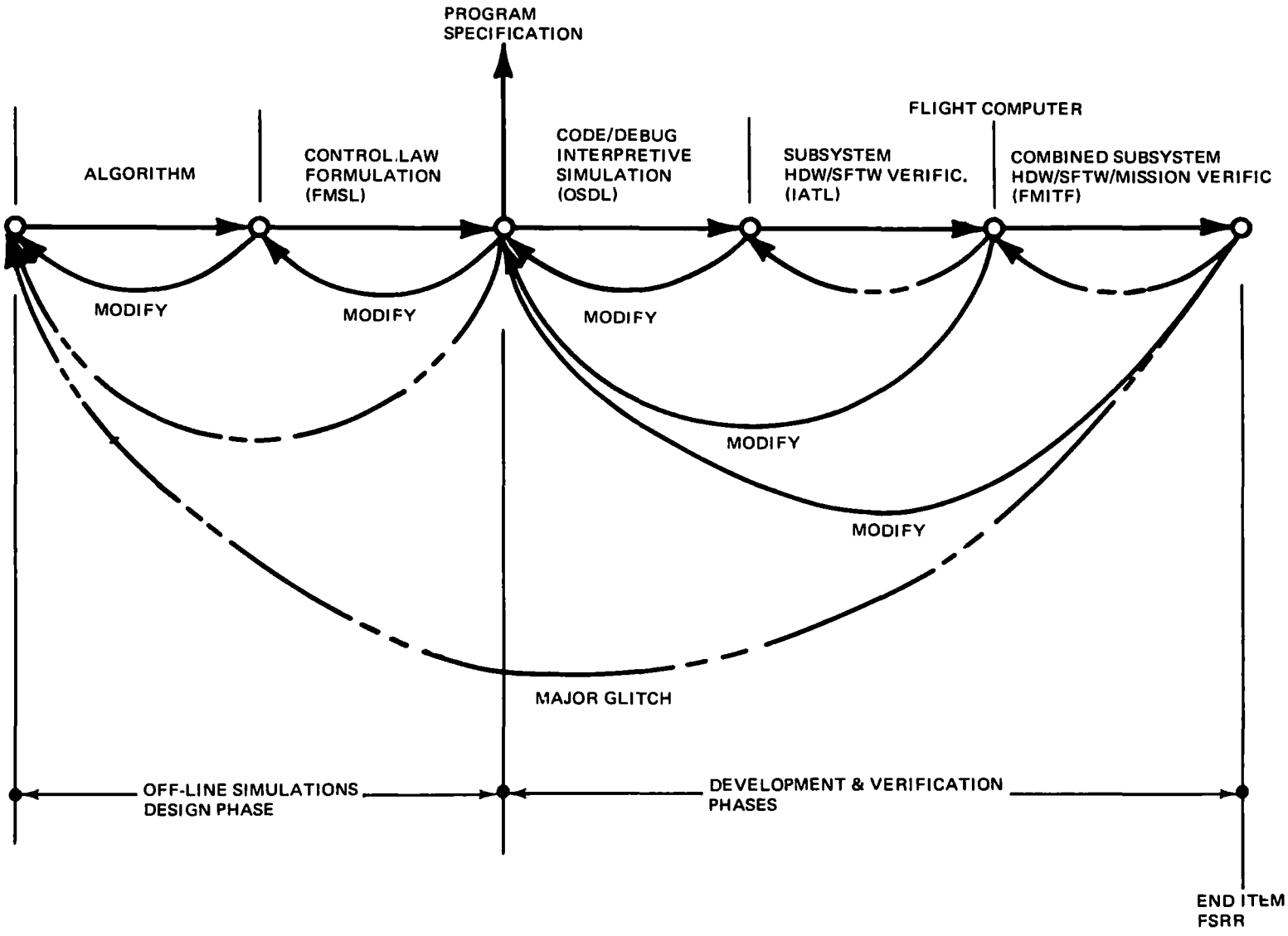


Fig. 1.12-4 Software Development Flow Graph

A separate and equally significant system integration software activity is the orbiter software development laboratory (OSDL). The OSDL permits design, development and test of computer programs required by the shuttle onboard computer systems. It should be noted that the OSDL is primarily a software development facility, however, software unit level and subsystem level testing and checkout will be accommodated as schedule allows. It is intended to develop an interpretive simulator on a large scale general purpose computer. An interpretive simulation technique was chosen because the computer provides the capacity for extensive analytical mission environment simulation in addition to simulating the onboard computer. Further, large scale computers have the availability of comprehensive peripheral equipment and debugging aids.

1.12.4 SOFTWARE ANALYSIS TASKS

1.12.4.1 Analysis Objectives

Software development planning, scheduling and implementation in support of vehicle engineering and development requires comprehensive analysis activities directed at identifying, defining and monitoring all software/software-related takks. A variety of interrelated analysis objectives must be satisfied by means of objective studies, evaluations and tradeoffs during the initial stages especially, and constantly re-appraised throughout development and operation. Such efforts will be documented and communicated through appropriate reports, recommendations or specifications.

The analysis objectives include:

- Cost effective selection of alternatives without degrading or compromising system requirements/system capabilities
- Reliability enhancement throughout project execution through detailed design, the application of a comprehensive test and verification philosophy and the satisfaction of quality standards
- Defining realistic design margins to provide adequate system growth potential and system flexibility
- Determination of commonality candidates through investigation and resolution within and among various software efforts to minimize costs and redundant efforts

- Timely performance of all levels of evaluations with participation of all effected elements
- Satisfaction of all system requirements; resolution of any inconsistencies, ambiguities, particularly poorly defined areas
- Provision for effective management control and visibility

1.12.4.2 Specific Analysis Areas

Specific areas of analysis are representative for the application of the analysis objectives. Because of the scope and magnitude of the major software baseline activities, these specific areas represent key decision tasks and are as follows:

- Computer system configurations: functional design and concept comparisons
- Computer system equipment selection
- Hardware/software tradeoffs
- Facility utilization, modification and/or fabrication
- Commercially available special/general purpose software packages
- Application implementation languages: assemblers/compilers
- Alternative software mechanizations, techniques
- Man-machine interaction

1.12.4.3 DMS Modeling and Computer Simulation (Operations Analysis)

The avionics data management/navigation and guidance computer complex and rapid reconfiguration computer complex (flight controls) concept development will be supported by a sustained modeling and simulation effort. A simulation computer program will be developed around the baseline configuration for operations analysis and study.

The simulation program will provide a dynamic, evolving analytic tool to support the evaluation of alternative design concepts and configurations and permit system projection investigations. Systems architecture will be modularly represented at the requisite component level reflecting all redundant elements.

The model will include the representation of the functional software organization and provide the analysis tool to investigate and evaluate control algorithms, resource allocation schemes, program modularization, data organization and relative priorities.

Simulation will be used to analyze system operation, component interaction/contention, interface activity, data bus loading, response time, resource utilization under various operating modes and environments, particularly heavily loaded mission phases and degraded system operation.

Characteristic element data (type, quantity, frequency) will constantly be improved and expanded with system design and development, with model growth. Data related to software elements (memory size, execution duration, etc.) will reflect current estimates or observations.

Quantitative analysis measures will be determined and utilized which are meaningful indications of performance and can be applied to the variety of trade study comparisons. Resulting performance measurement data will be used to monitor requirements satisfaction and the exhaustion of initial design margins for management awareness, control and visibility.

SYSTEMS ENGINEERING & INTEGRATION

Section 2

SYSTEM ENGINEERING AND INTEGRATION

This section defines the tasks involved in the detailed design and development of the orbiter system. These tasks are concerned with technical people and analytic processes that are part of a system engineering management plan used successfully in such programs as LM, OAO and the F-14.

The system engineering and integration efforts described in this section assure a design that is technically adequate and cost effective. The Grumman approach not only leads to a sound detailed design of the orbiter vehicle and related support but also provides interface design for the booster and its support.

The tasks of the "Basic Analytic" disciplines (Fig. 2-1) will be generated within the framework of the general system engineering task flow shown in outline form in Fig. 2-2. This approach provides for:

- A definition of system performance parameters and of system hardware configuration through the use of an iteration process of definition, analysis, synthesis, and design
- The integration of related technical parameters and assurance of compatibility of all physical, functional, and program interfaces in a manner which aims toward optimization of total system definition and design

Figure 2-1 shows the major relationship between the informational inputs and the various disciplines, the planned tasks of which are described in subsections 2.1 through 2.20 of this volume.

All of the disciplines described respond in varying degrees to the informational inputs; however, the labelled "Basic Analytic" disciplines emphasize those concerned with analysis leading to some form of hardware/software design, while the other set is concerned with a reaction to these analytic outputs to assure such factors as verification,

quality, safety, weight, and cost effectiveness. These reactions provide feedback to the analytic efforts resulting in changes, modifications, negations, or approval.

Summarizing, it is the goal of the system engineering and integration effort to develop systematically the design requirements of the orbiter system, cost effectively, within the scheduled time, through the use of a logical concept of task flow in which the efforts of a number of disciplines are suitably integrated.

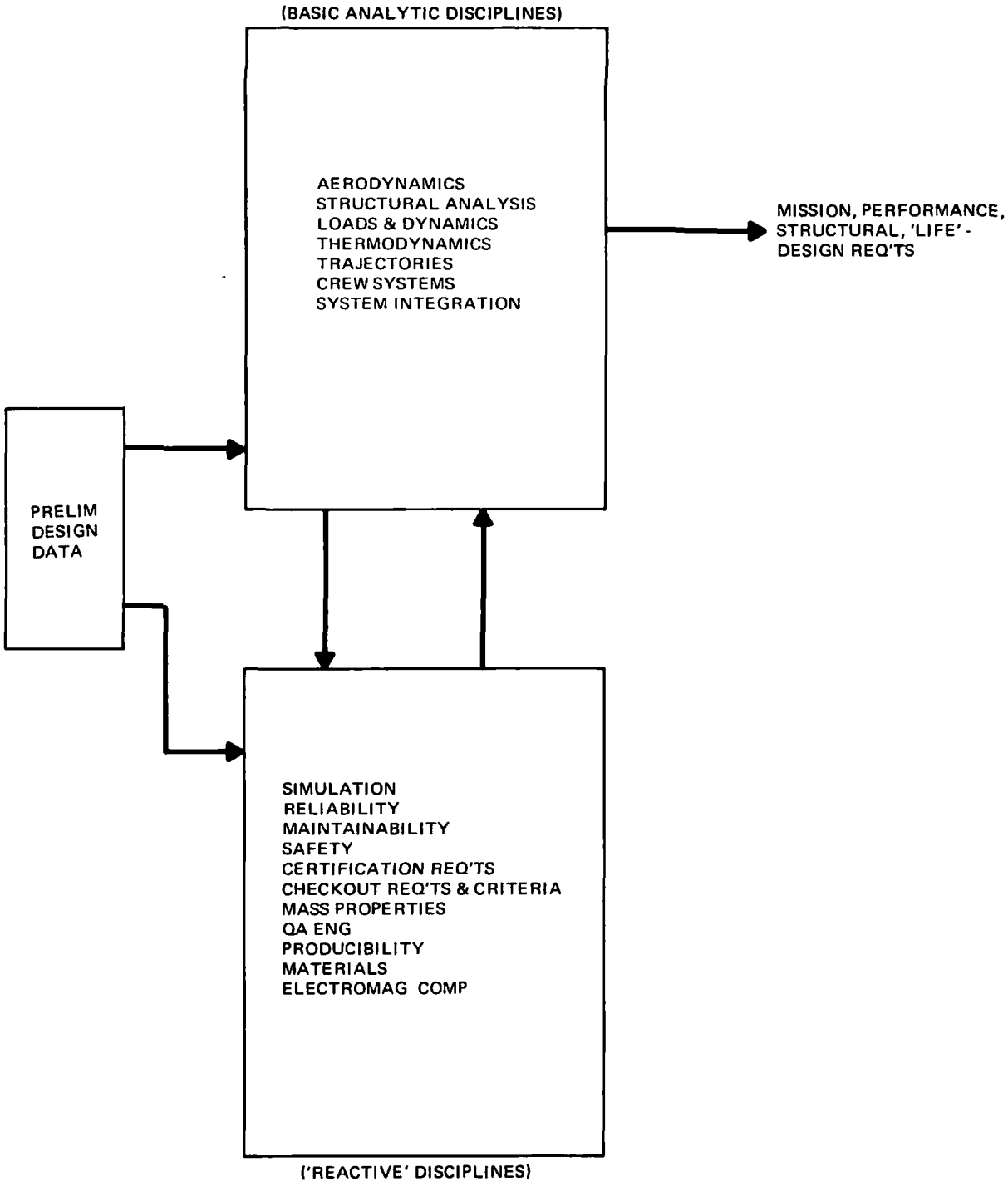


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Fig. 2-1 Discipline Relationship Diagram

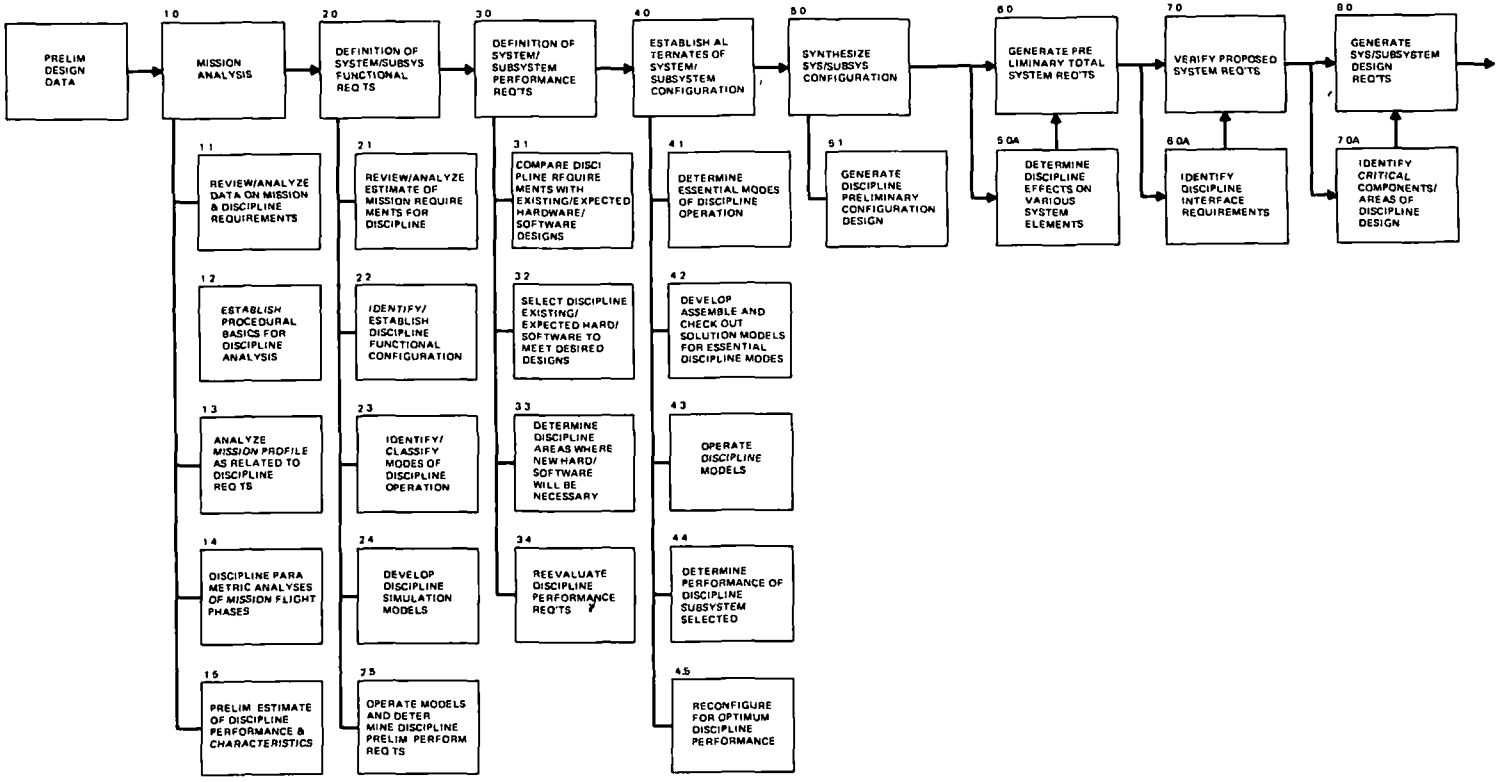

Fig. 2-2 System Engineering Task Generation Logic

2.1 RELIABILITY

A comprehensive, cost-effective reliability program has been formulated and will be implemented during Phase C/D of the orbiter program to ensure compliance with the specified program requirements and with applicable portions of NHB 5300.4 (1A). This program, which will be further refined during Phase C/D, is contained in the preliminary Reliability and Maintainability Program Plan. It defines major tasks and establishes effective reliability control techniques. Performance of these tasks has been scheduled at appropriate critical points during the design, development, production, and operational phases. Implementation of this plan will assure close surveillance and control of this effort, timely completion of the tasks, and attainment of the desired end-product reliability.

2.1.1 RELIABILITY CONTROL

Control begins with a review of the initial system design concept and continues throughout the various program phases. Significant control activities include the following:

- Configuration and tradeoff analyses to compare the relative reliability of alternate designs
- Surveillance/analysis of detail design, testing, and operation to estimate and measure reliability at all levels; compare with requirements and identify problem areas
- An economical, balanced parts program designed to standardize, coordinate and control the total parts/materials effort on the orbiter program
- A comprehensive, cost-effective test program consisting of development, qualification, selective reliability demonstration, and acceptance tests planned to identify equipment deficiencies, verify design integrity, and provide maximum reliability assurance
- Performance of Failure Mode and Effects Analyses (FMEA's) on flight hardware, at the mission, subsystem and equipment levels to determine effect of possible failures on overall system operation, identify degraded modes of operation and Single Failure Points

- GSE interface FMEA's to identify failure modes that could result in personnel injury, induce or fail to detect flight hardware failures, or cause launch delay
- A closed-loop failure analysis and closeout system to provide adequate corrective action and timely resolution of equipment problem areas
- An existing totally integrated Reliability and Maintainability Data Tracking System which is an extension of the LM system is presently in operation on all existing in-house aircraft programs (F-14, EA-6B, A-6E, E-2C) and is readily adaptable to anticipated orbiter requirements with minimal development costs

2.1.1.1 Parts and Materials Program

2.1.1.1.1 General

The orbiter Parts and Materials Program will blend basic tools and controls planned and currently being implemented on Grumman space and aircraft programs. Emphasis will be placed on a cost effective approach, particularly in the areas of parts selection and screening. The result will be a comprehensive and balanced approach that will include innovations as well as the conventional tasks of NASA NHB 5300.4(1A).

2.1.1.1.2 Design Coordination

Grumman will offset the problems inherent with a large number of equipment sellers with diverse geographic locations by the establishment of a Parts Control Board. This Board, consisting of representatives of Grumman and major subsystem sellers, will invite the direct participation of NASA. Its function will be to:

- Assure orbiter system parts/materials coordination and standardization
- Develop common policies and procedures
- Establish and maintain the preferred parts list
- Exchange parts data of common interest
- Provide a common ground for discussion and resolution of part problems

2.1.1.1.3 Program Indoctrination

Grumman experience has shown that strong indoctrination of seller's management and design personnel is mandatory to prevent a high percentage of part rejections and replacements during the early design phase. These indoctrination sessions are necessary to clarify ambiguities and to emphasize the risk of part rejections in the event of noncompliance to Grumman requirements.

2.1.1.1.4 Parts and Materials Evaluation and Control

The various orbiter design and environmental constraints (e.g., long life, flammability, vacuum, thermal shock and radiation) dictate general and specific policies regarding the following tasks:

- Selection/Application - The Preferred Parts List will have precedence over all other documents. The basis for selection will be demonstrated suitability for the intended application and adequate derating in compliance with Grumman Part Derating Policies. To ensure system integrity, part deviations and substitutions will be strictly controlled
- Qualification, Lot Sampling Inspection and Screening - Grumman experience has shown that statistical qualification and lot sampling tests are extremely expensive and less effective than 100 percent screening. The Grumman part test philosophy for orbiter will emphasize part screening requirements, while de-emphasizing both part qualification and lot sampling tests. The cost effective approach will be to qualify parts by one or more of the following methods:

  1. Part Level

     - Similarity (GIDEP and other data)
     - 100 percent screening to applicable Hi-Rel specifications including accept/reject criteria
     - Mini-Qualification

2. Higher Level Test

- Development: step-stress
- Qualification: black box/subsystem
- Reliability demonstration

2.1.1.1.5 Parts and Material Problems

These problems will be resolved in line with Grumman procedures as follows:

- Failure Analyses - Part/material failures occurring during DVT (Design Verification Tests) and during/after equipment acceptance tests will be analyzed. Grumman experience indicates that analysis of failures during DFT (Design Feasibility Tests) are not necessary. Parts known to have exceeded their expected life will not be analyzed.
- NASA/GIDEP ALERTS - Grumman will evaluate part and materials problems circulated by either NASA or GIDEP to determine relevancy to this program. A formal closeout system will be in effect to ensure accelerated resolutions prior to any launch. Grumman will also inform GIDEP when a significant problem not yet reported is encountered.

2.1.1.2 Test Program

All hardware will be certified for flight in accordance with the requirements of the program described in subsection 2.5.

Certification will be accomplished through selective qualification, delta component and subsystem tests, flight tests, similarity and analytic techniques or combinations of these. Results from analyses (failure mode and effects, weak link, and criticality and environmental) and past history investigations will be compared to orbiter requirements to establish the method of certification.

The orbiter test program provides maximum reliability assurance in a cost effective manner by using test concepts and techniques developed by Grumman and proven on both space and aircraft programs. It will include the following elements:

- Strong, early development effort to verify design integrity in a timely manner. This test phase will include: design feasibility and verification tests to verify basic designs and materials used and evaluate equipment performance; overstress tests to define safety margins and identify weak design links
- A qualification test effort incorporating these proven elements:
  - Test at highest level practicable
    - . Generally more economical
    - . Environmental evaluation of interfaces
  - Realistic simulation
    - . Critical, anticipated environments
    - . Operation and equipment monitoring during exposure
  - Strong program control to ensure proper corrective action and retest requirements and incorporation of the appropriate change in flight hardware to preclude recurrence
- Acceptance under selected environments will be performed on all equipment to eliminate manufacturing defects and assure proper remedial action for all failures

2.1.1.3 Reliability and Maintainability (R&M) Orbiter Data System

The Orbiter R&M Data System is a fully developed and operational reporting system. It is based on the LM Data Collection and reporting system, expanded to meet the needs for measuring and tracking operational life characteristics and includes data elements of aircraft hardware systems. The LM system was strictly reliability oriented and did not

require maintainability data elements (report collection, processing, and feedback and corrective action). Consequently, the Orbiter Data System includes additional elements and provides for collection and assessment of such values and measures as:

- Failure/time densities
- Mean-time-to-repair (MTTR)
- Elapsed maintenance time
- Levels of maintenance
- System uptime and downtime

These factors will have a direct bearing on the system performance, service life, turn-around and sparing requirements for the orbiter.

The system is capable of processing, tracking, and managing all levels of R&M raw data from system to piece-part, and in all test environments including flight. Minimal modifications are expected to existing forms and processing techniques for use on the orbiter program, thereby eliminating development and excessive programming and systems debugging costs. Output files, as well as any reports developed therefrom, will be completely compatible with NASA requirements and reporting, as a minimum.

2.1.2 ANALYTICAL TECHNIQUES

As an integral part of the orbiter engineering effort for Phase C/D, reliability analytical techniques of a quantitative and qualitative nature, will be used to evaluate alternate design concepts and provide the necessary insight into the identification and solution of potential problem areas. These analyses will also provide NASA and Grumman management the techniques with which to optimize the vehicle and mission definitions with respect to performance and cost, as a function of various parameters (e.g., equipment reliability, availability of redundancy, elimination of critical failure(s), etc).

Based upon the subsystem and mission definitions generated during Phase C/D the following analyses will be performed:

- Failure Mode and Effect Analyses and Critical Failure Summary - Each subsystem and system interface, including those between the booster, the orbiter, and the payload, as well as those between the SSV and preselected Ground Support Equipment will be analyzed to determine the effects of postulated failures on the mission performance, the safety of flight/ground personnel and the adherence to the NASA preestablished failure criteria (e.g., FO/FO/FS; FO/FS, etc). For each postulated failure or sequence of credible, interrelated failures, the mission consequences, available detection and/or compensating provisions inherent in the orbiter design will be identified. Recommendations to eliminate or minimize the effect, modify the detection techniques and/or identify additional alternative mission modes will be made to appropriate NASA/Grumman personnel

- Reliability and maintainability simulations, multistate effectiveness, and optimization models developed by in-house advanced technical development studies will be used during Phase C/D to enable analysts to optimize levels of redundancy, modes of operation, levels of maintenance, etc., for particular orbiter designs, redundancy management techniques, in-flight checkout capability and available alternate modes of operation. The models will permit the determination of the relative value of such alternatives within the constraints of cost, weight, power, element reliability, risk, and effective payload-to-orbit. Preliminary analyses of orbiter avionic subsystem redundancy requirements show that an application of Grumman's redundancy selection techniques resulted in a significant weight and cost savings with no compromise in system reliability over techniques using arbitrary redundancy selection criteria.

- Failure Analysis - During Phase C/D, Reliability is a focal point for receiving, reviewing and disseminating failure information. We will participate in the performance and/or review of the failure analysis performed at various facilities. The analysis will require the implementation of state-of-the-art techniques to define the mode and cause of each failure. The adequacy of the recommended corrective action to assure nonrecurrence of the failure will be reviewed and approved by reliability personnel in conjunction with other cognizant design groups.

2.1.3 COMMONALITY CANDIDATES

The following elements of the reliability program are candiates for common orbiter/booster implementation during Phase C/D.

- Parts Program (2.1.1.1)
- Test Program (2.1.1.2)
- Reliability/Maintainability Data System (2.1.1.3)
- Analysis Procedures (Predictions, FMEA, Design Review, Failure Closeout System, etc)

2.1.4 FACILITY REQUIREMENTS LIST

In support of the Parts and Materials Program, the following existing facilities will be used:

- The Grumman Failure Analysis Laboratory will perform failure investigations as required and establish failure modes/mechanisms of failed parts and materials
- GIDEP (Government Industry Data Exchange Program).

2.1.5 COMPUTER SUPPORT REQUIREMENT

To provide for the storage and retrieval of malfunction/maintenance data and reports (e.g., failure and maintenance action summaries, parts usage data, equipment shelf life/limited life status, etc.) and execute optimization programs, as defined previously, the computer facilities and programming and services of the Grumman Data Systems Corporation will be required.

It is anticpated that many of the reliability/maintainability data management systems and computational algorithms previously developed for other programs or under specific Advanced Development studies will require only minor modifications in order to be applicable to the orbiter program.

Depending on the particular NASA requirements for Phase C/D, the formats of present failure summary reports, parts usage lists and equipment shelf life/limited life status lists will be modified as necessary to reflect orbiter applicability.

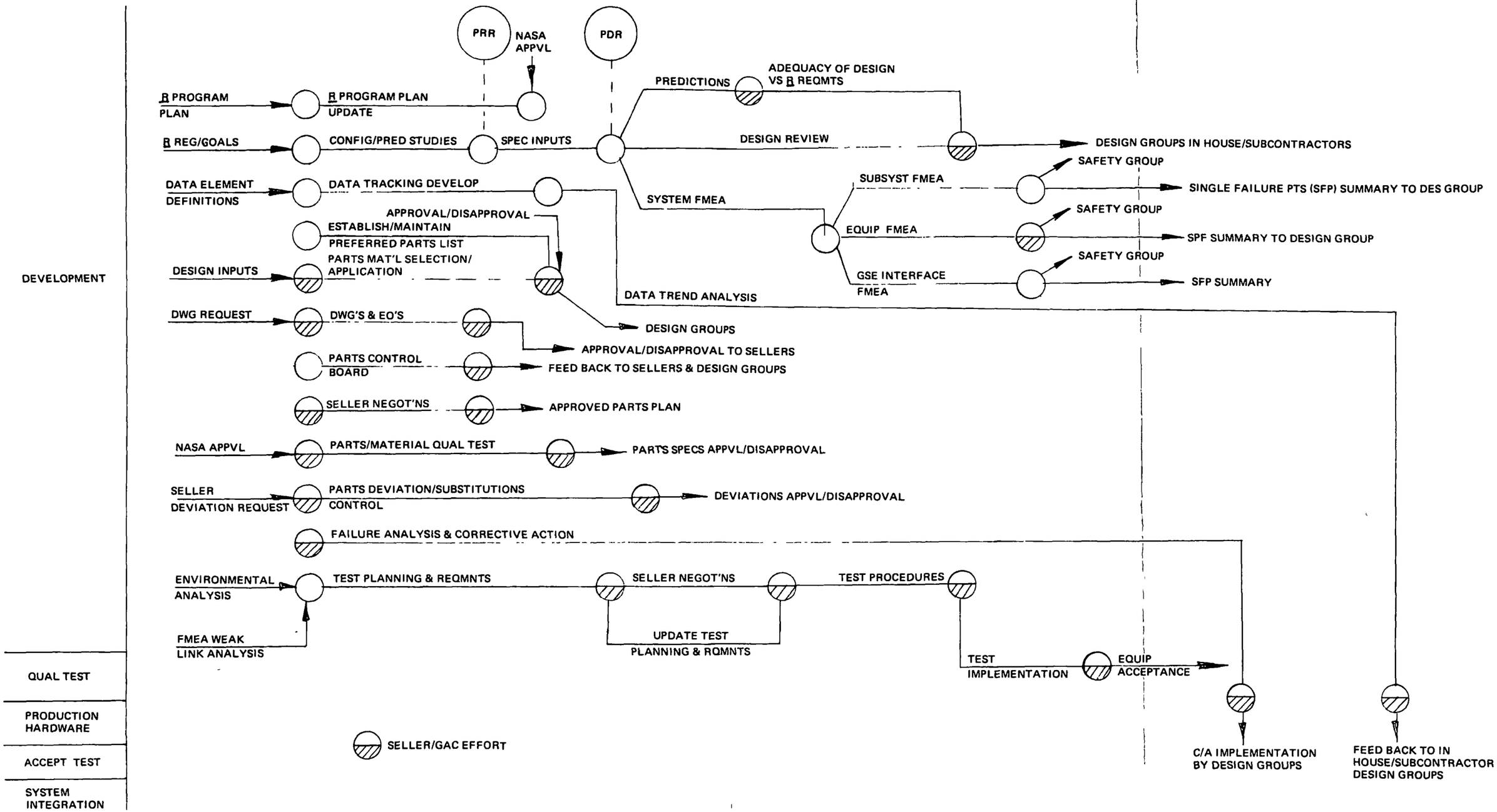

Fig. 2.1-1 Reliability Logic Network

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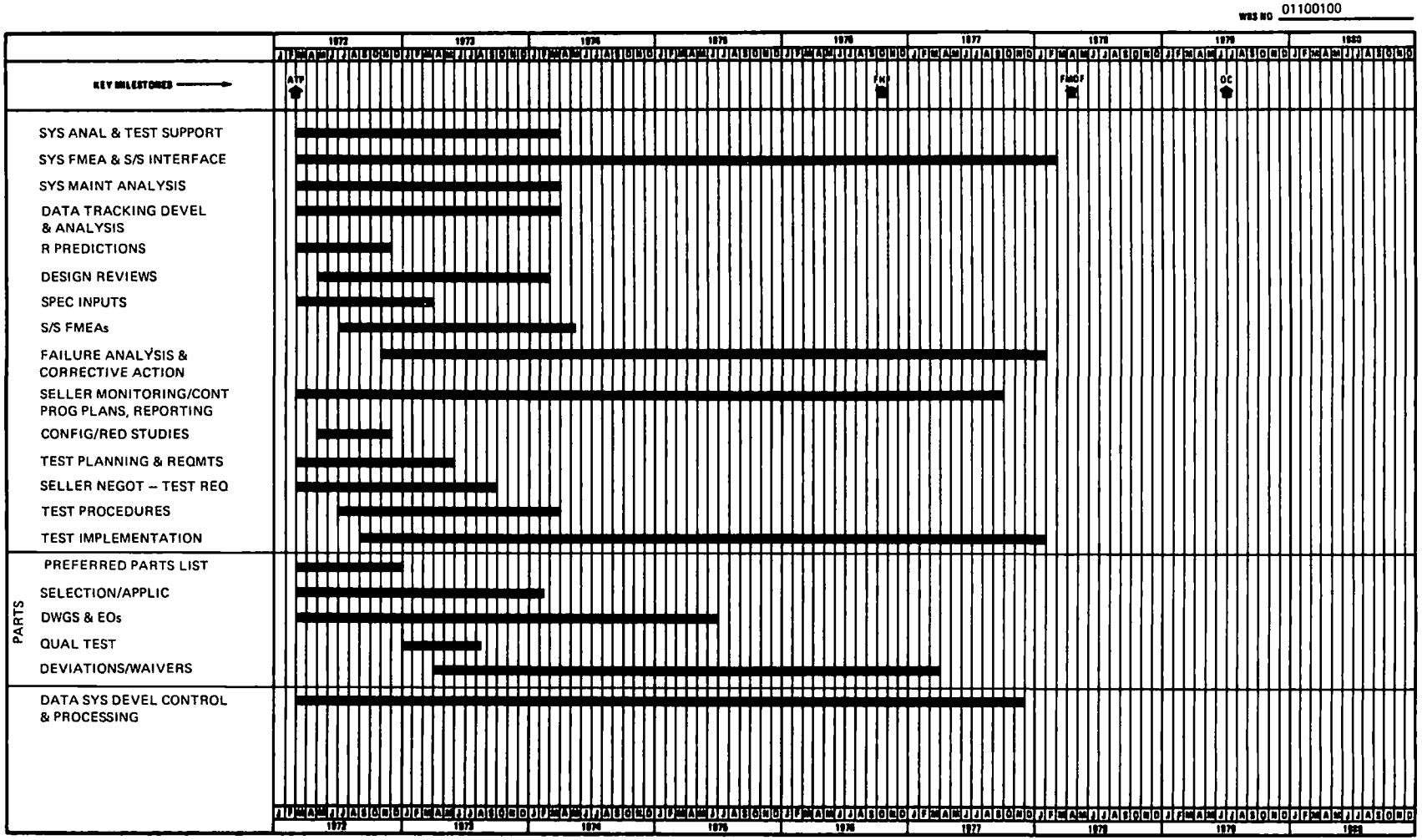

Fig. 2.1-2 System Analysis and Integration Reliability Schedule

2.2 MAINTAINABILITY

The objective of the orbiter maintainability program is to assure that the design meets:

- 14-day turnaround
- 48-hour rescue launch readiness
- 2-hour launch readiness from standby
- 100 missions/10-year life
- Low cost

2.2.1 MAINTAINABILITY APPROACH

The basic approach is to use modern aircraft maintainability concepts, modified by the special operational requirements of the orbiter to meet the program objectives of low-cost turnaround. Our approach is based on long experience with stringent DOD operational requirements in connection with Grumman military aircraft programs and Eastern Airlines experience in operating large fleets of modern commercial transport aircraft. As an example, the Navy's new air superiority fighter, the F-14, must be capable of being maintained within specific maintenance-man-hour per flight-hour constraints, and must be turned around within 30 minutes after landing. Other time-segmented and performance restrictions that must be satisfactorily demonstrated are; mean time to correct all discrepancies after a single flight of 1.6 hours, and an operational readiness test time of 6 minutes to determine system status. These quantitative requirements were prime movers in designing the F-14 for maintainability.

The orbiter maintainability approach will include assessment of ground checkout through automated testing and determination of the necessary corrective and preventative maintenance time intervals required during turnaround. In addition, the repairability aspects of LRU's during off-line shop level repair will be considered. Design analyses, tradeoffs, and reviews will be performed to determine optimum maintenance policies and to assure incorporation of design features such as accessibility, modularity, automatic built-in-test and on-board checkout for fault detection and isolation to meet turnaround requirements.

2.2.1.1 Subsystem Maintainability Considerations

- Modular Design - The design of maintainable equipment will stress ease of malfunction detection, isolation, removal and replacement and verification at a relatively high level of assembly. Replaceable modules will permit decoupling of maintenance tasks from the vehicle, allowing detail repairs to be performed off-line. Modularization in the H33 configuration even includes such large elements as the Orbital Maneuver System (OMS) and Main Propulsion Subsystem (MPS) cryogenic tanks. The main hydrogen tanks are external and are expended during orbital operations. The main oxygen tanks are nonintegral (floating) and accessible for removal for major inspection and/or repair through the removable nose structure. The OMS hydrogen tank is located in the removable nose and is also accessible. The OMS oxygen tanks are located aft, and accessible through a panel in the floor of the payload bay. These design features will assure that the two-week turnaround can be met, even if major inspection and/or repair must be accomplished on these tanks. The level of replacement for all equipments will be the subject of tradeoffs between removal and replace time and total maintenance costs
- Onboard Checkout (OBC) - OBC will isolate failures to a reconfigurable level to allow redundancy switching during the mission. For the majority of subsystems, this will allow unambiguous fault isolation to a malfunctioning Line Replaceable Unit (LRU) to assist the maintenance function. Diagnosis of the LRU will not be a requirement of OBC. Diagnosis will be accomplished off-line, in support shop areas. OBC will verify that redundant equipments are in operable state. This feature will permit missions to be launched with certain prime equipments degraded, thereby protecting launch schedules. The system will include built-in-test (BIT) devices, so that the operational status of equipment, both mechanical and avionic may be determined.
- Accessibility - Accessibility will be provided to assure adequate maintenance in either the vertical or horizontal position.

- Reusability - Special emphasis will be placed on all items that require replacement or refurbishment after each mission, or at some predetermined interval. All items not reusable, or designed for a limited number of mission cycles, will be designed for quick change

- Maintenance Policy - A determination of the optimum maintenance policy to be employed for the orbiter will be made by performing tradeoff studies between equalized and periodic maintenance. In addition, a time extension program for installed components, and repair versus throwaway will be studied

2.2.1.2 Maintainability Program

A maintainability program has been formulated and is contained in the preliminary reliability and maintainability program plan. This program which will be updated during Phase C/D, has been structured to follow a logical sequence of tasks and provide the necessary management controls. Measurable maintainability parameters will be defined to assure that the basic requirement for the two-week turnaround can be achieved. The parameters will be partitioned and budgeted to the various subsystems and equipments to permit establishment of design criteria for each subsystem/equipment. Maintainability engineers will work with the designers during the early design effort to assure incorporation of those features required to meet the budgeted maintainability parameter values. Additionally, maintainability requirements are included in seller specifications to assure that equipment designs provide for cost-effective level II and III maintenance by incorporation of design features such as fault isolation, detection, accessibility, modularity, interchangeability and elimination of sources of human induced errors. Maintainability analyses will be performed to assure that the developing designs are compatible with the requirements, and also provide the basis for logistic and support planning. Maintainability will participate in design reviews to assure that the established criteria have been met.

Achievement of specific maintainability objectives will be verified and demonstrated on mock-ups and during early development flights. A system of malfunction analysis and program tracking will be implemented to provide feedback into design and assure that adequate corrective action is taken to resolve problems encountered during early operations.

Specifically, some of the tasks that will be performed that are delineated in the R&M Plan are as follows:

- Derivation of specific subsystem/equipment maintainability requirements from the overall program requirements
- Perform maintainability analyses
- Provide inputs to maintenance concept and maintenance plan
- Establish maintainability design criteria
- Perform design tradeoffs
- Predict maintainability parameters
- Incorporate and enforce maintainability requirements in seller specifications
- Participate in both in-house and seller design reviews
- Define scheduled replacement and/or service requirements based on life-limited characteristics
- Demonstrate achievement of maintainability requirements
- Prepare maintainability status/progress reports

2.2.2 ANALYTICAL TECHNIQUES

2.2.2.1 Mathematical Models

- Level of Maintenance Model - Used to perform tradeoffs which determine effects of levels of maintenance with respect to cost, weight, space, maintainability criteria, etc., while meeting fail operational and fail safe requirements
- Turnaround Model - Assists in determining optimum maintenance policies as a function of turnaround time, maintenance and support resources, reliability/maintainability parameters and mission demand frequency
- GO/NO-GO Operational Decision Criteria - Used to develop decision rules concerning launching with inoperative equipment and may be used to develop minimum operating equipment requirements for launch (Minimum Equipment List)

2.2.3 COMMONALITY CANDIDATES

The following elements of the Maintainability Program are candidates for common orbiter/booster implementation during Phase C/D.

- Operating maintenance plan
- Analysis procedures
  - Level of maintenance model
  - Turnaround model
- Reliability/maintainability data system (subsection 2.1.1.3)

2.2.4 FACILITY REQUIREMENTS LIST

None required.

2.2.5 COMPUTER SUPPORT REQUIREMENTS

An existing integrated malfunction/maintenance data system, as described in subsection 2.1.1.3, will satisfy both the reliability and maintainability program requirements, and is proposed for implementation during Phase C/D. Accordingly, the computer support requirements, as delineated in subsection 2.1.7, apply.

In addition, the assistance of Grumman Data Systems will be required to develop specialized subroutines and formats for the initial application of the level of maintenance and turnaround models previously discussed.

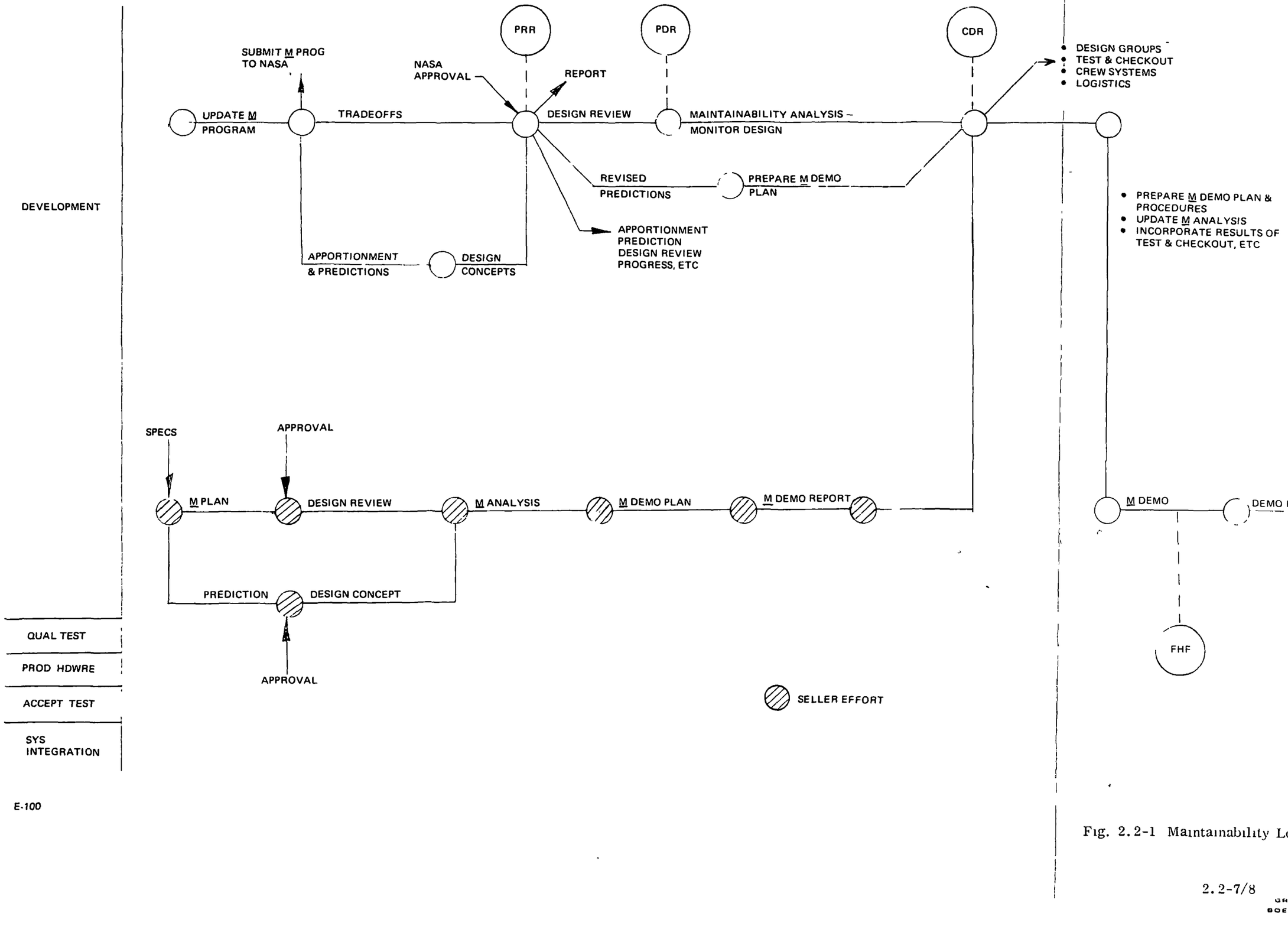

Fig. 2.2-1 Maintainability Logic Network

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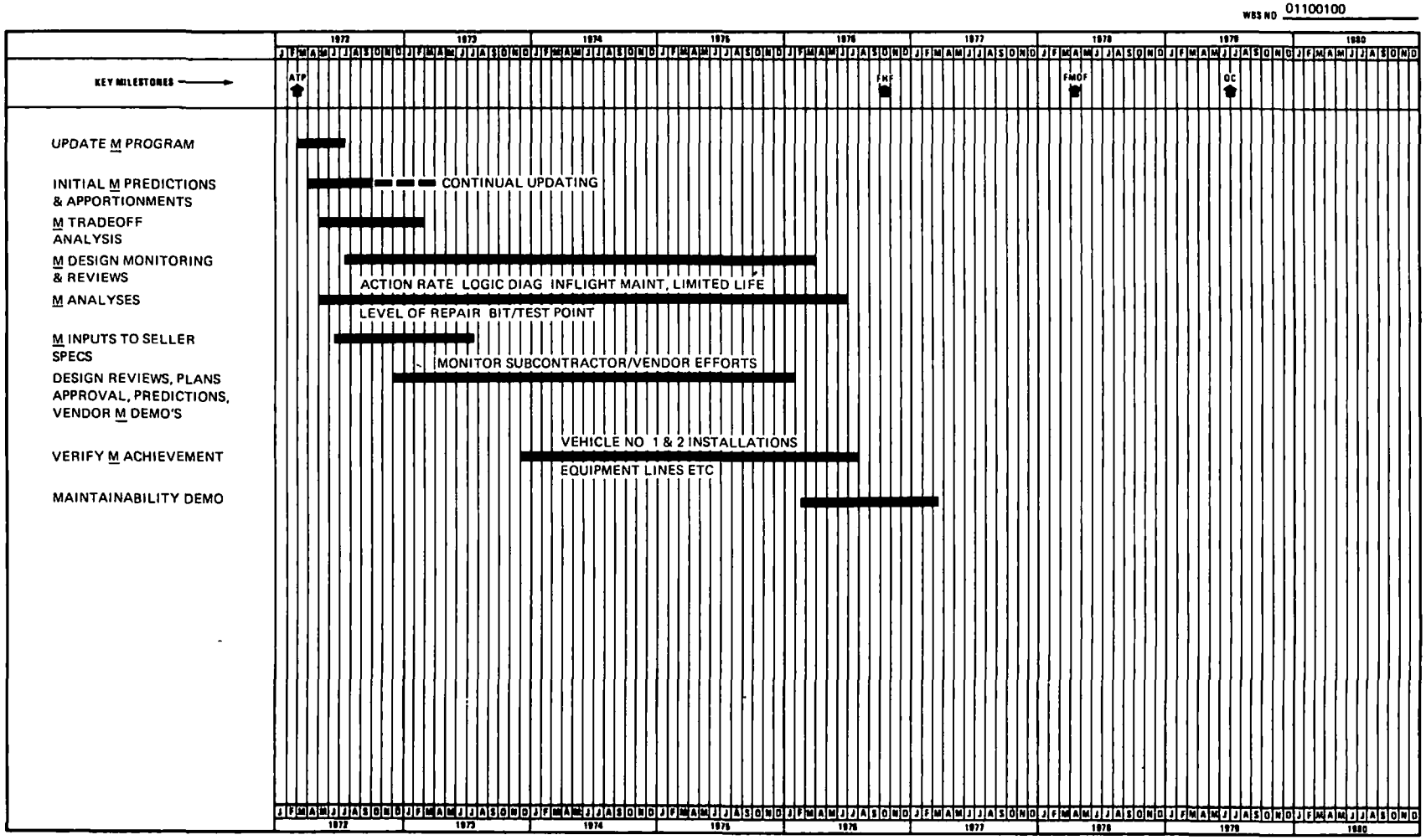

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Fig. 2.2-2 Systems Analysis and Integration Maintainability Schedule

2.3 SAFETY

2.3.1 TASK DESCRIPTION

Safety defines design requirements and operational constraints aimed at controlling risks to mission success and preventing accidents and incidents. The major functions that will be performed, as defined by the MSC "System Safety Program Requirements for Space Shuttle Contractors (Preliminary)", include:

- Hazard Analyses
- Safety and Trade Studies
- Hazard Data Collection, Analysis, and Corrective Action
- System Safety Implementation Assurance
- Safety Training and Certification
- Procedures and Operations Review and Evaluation

Fig. 2.3-1 presents the major tasks related to the above functions. It shows how these tasks support the formal reviews and the program life cycle. The Safety Plan, No. 552-43-RP-8, provides detailed information on the individual tasks.

2.3.2 SAFETY ISSUES

Safety issues were identified during the conduct of the Phase A hazard analyses that have significant impact on shuttle design and operations. They were selected because good design characteristics and prescribed procedures may not eliminate the risks they represent. Typical issues are identified below. The approach Grumman will take to resolve them is also discussed.

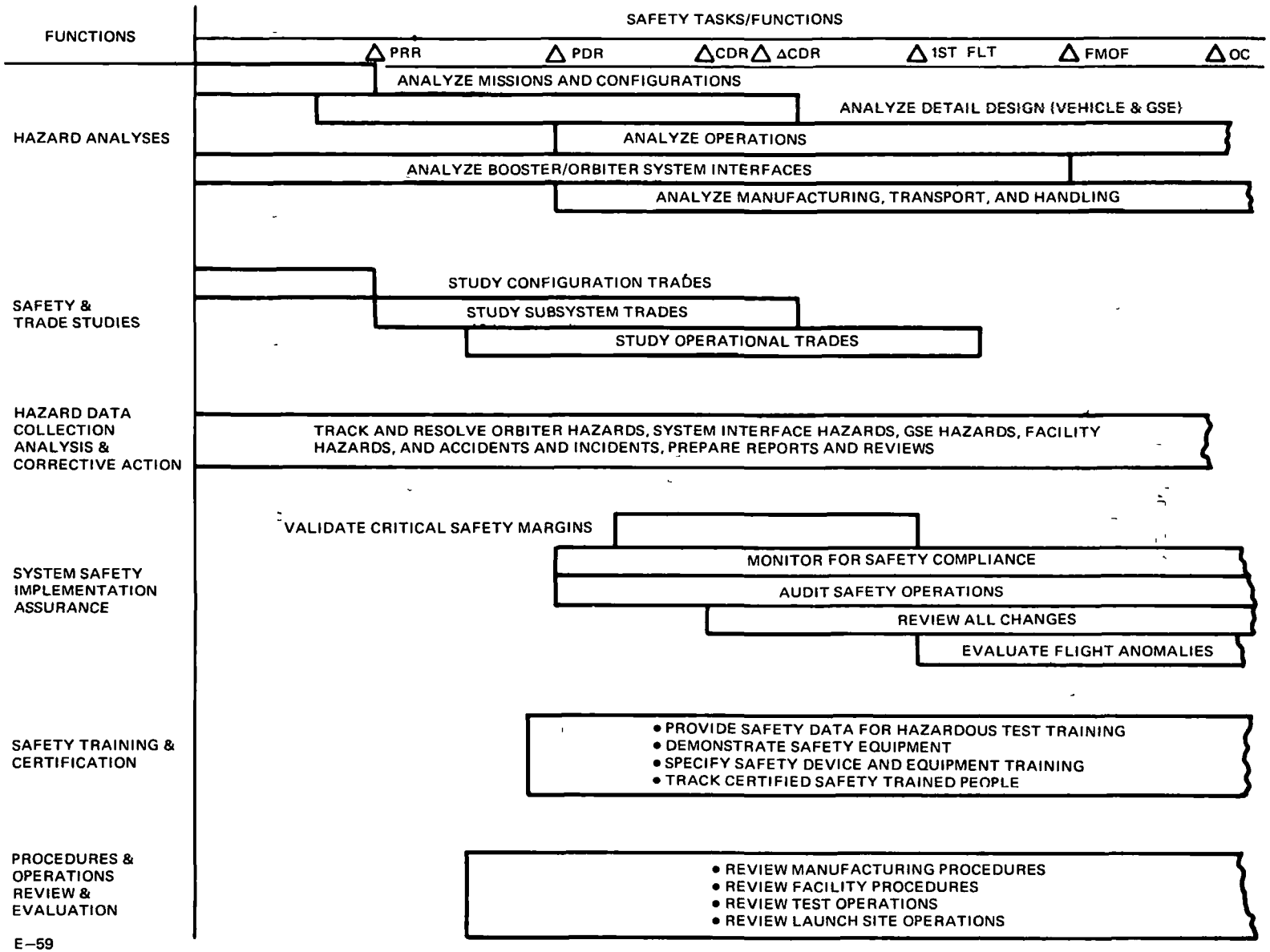

Fig. 2.3-1 Safety Tasks/Functions

2.3.2.1 Launchpad Emergencies

One of the most crucial regions in the entire mission is the period from cabin close out to achievement of the minimum safe abort altitude. Corrective measures, which minimize the hazards to crew, passengers, and vehicles, are developed for the following periods:

- Cabin close out to engine ignition
- Ignition to tie down release
- Tie down release to minimum safe abort altitude

Safety analyses are performed to identify the specific design or operations measures to use in each of the above periods. Stress is placed on common crew procedures, where this is feasible.

2.3.2.2 Crashworthiness

Landing accidents in the fatality-from-fire-after-touchdown category can stem from factors beyond the control of the vehicle designer. Lack of navigation aids at a landing site is one typical factor. To minimize the probability of a landing accident, good low-speed flying qualities that assure adequate pilot control during landing are a must. Jettison of the main hydrogen tanks prior to landing eliminates one major fire-after-hard-landing hazard source. To guarantee crew/passenger survival in the remote case of a hard landing, current Grumman standards are applied to seat design and cabin structure.

2.3.2.3 Certification for Reuse

Flying with failures in noncritical equipment will be acceptable if the level of redundancy in safety of flight systems is adequate. To provide assurance that the vehicle is ready for flight, two things must be done:

- Identify the safety checks which are mandatory before rollout, erection, mating, and launch.
- Establish the inspections necessary after maintenance has been performed.

The ability to test large volume propellant tanks (external and removable internal tanks) independent of the basic vehicle is a safer mode of operation because a tank failure during re-test off the vehicle would not subject the parent vehicle to damage. Better and more rapid tank repairs are possible and rapid turnaround is enhanced.

2.3.3 LOGIC AND CONSTRAINT NETWORK

Fig. 2.3-2 presents the safety network for shuttle development, production, flight test, and operations program phases. It demonstrates the iterative nature of hazard analyses, support of the prime design loop, as well as mockup reviews, manufacturing, flight test and operations. Feedback from test and flight missions may initiate changes to be analyzed for hazards. The result of this analysis is used to support the design change and the next readiness review.

2.3.4 ANALYTICAL TECHNIQUES

The hazard control system is shown in Fig. 2.3-3. It features a review of critical corrective actions for program impact by the Safety Board, incorporation of safety requirements via the systems design handbook, tracking of all hazards once identified through all phases of the project, and an assessment of residual risks by the safety board. The system has worked in the past; only the Safety Board is new.

Accident/incident control is shown in Fig. 2.3-4. Once the situation that occurred is safed, the proper notifications are made and the type of investigation is determined. Investigation results applicable to other centers, sites, and design elements are relayed to them to preclude recurrence of the accident/incident. The system has worked successfully on LM for several years.

2.3.5 BARCHART SCHEDULE

Fig. 2.3-5 represents the scheduled safety task milestones and their relationship to project milestones.

2.3.6 CERTIFICATION REQUIREMENTS

Safety certification requirements for major interface design validation are shown in Table 2.3-1.

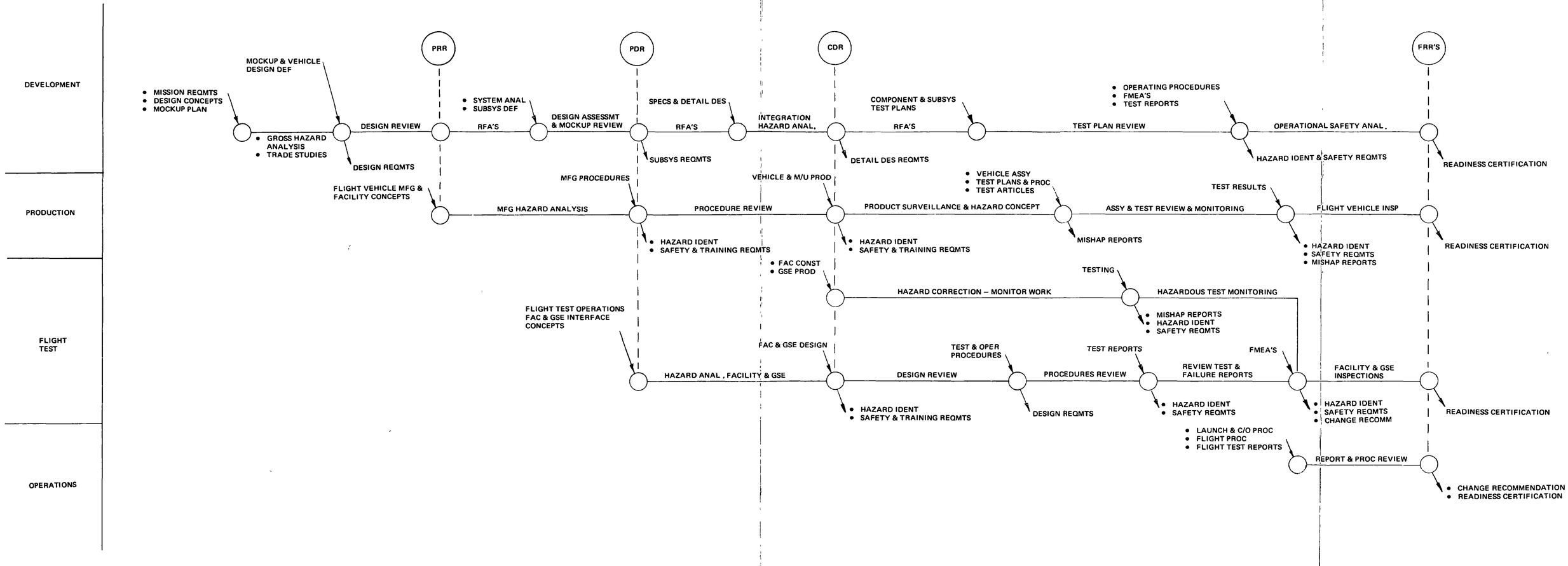

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Fig. 2.3-2 Safety Logic Network

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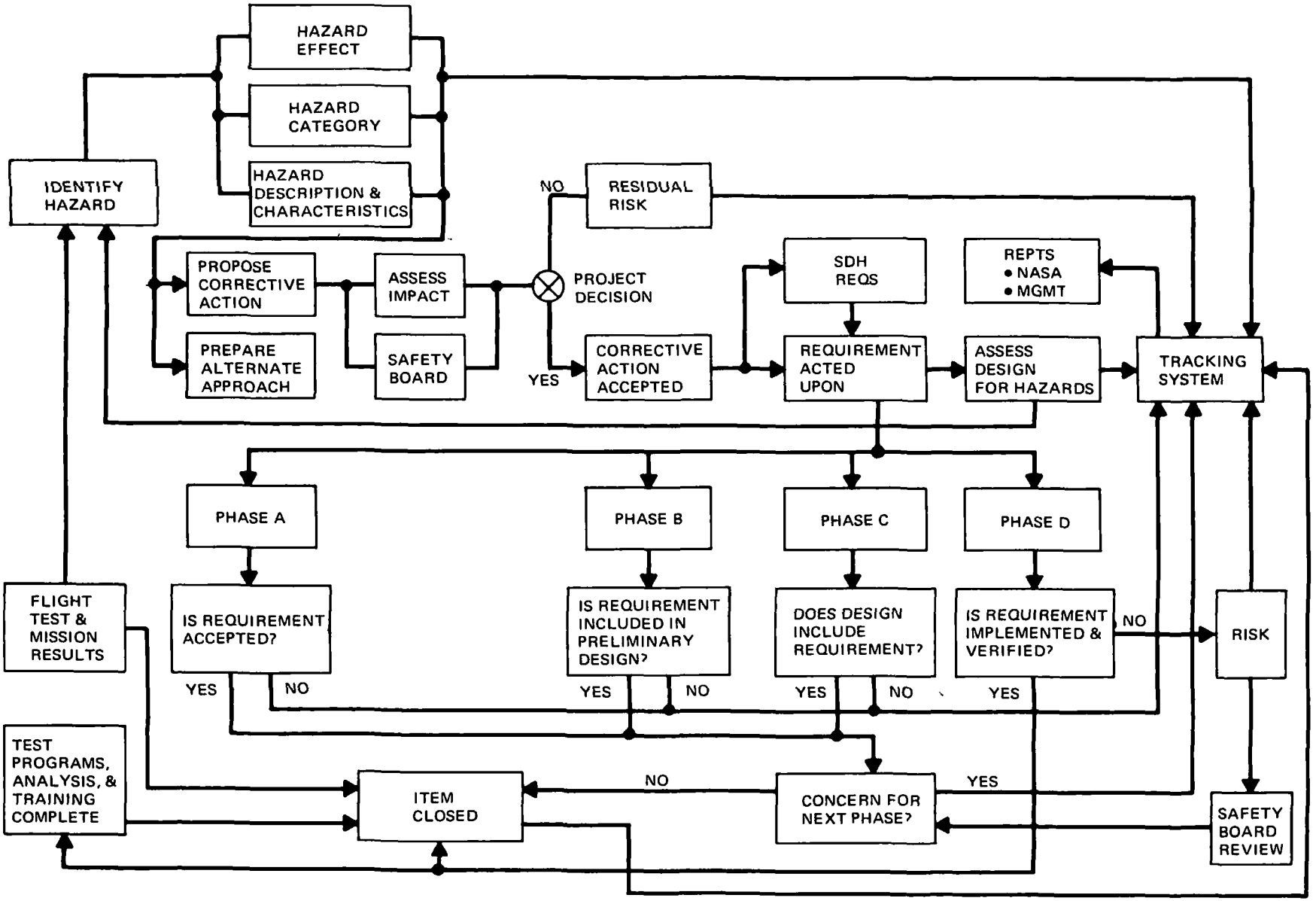

Fig. 2.3-3 Hazard Control System

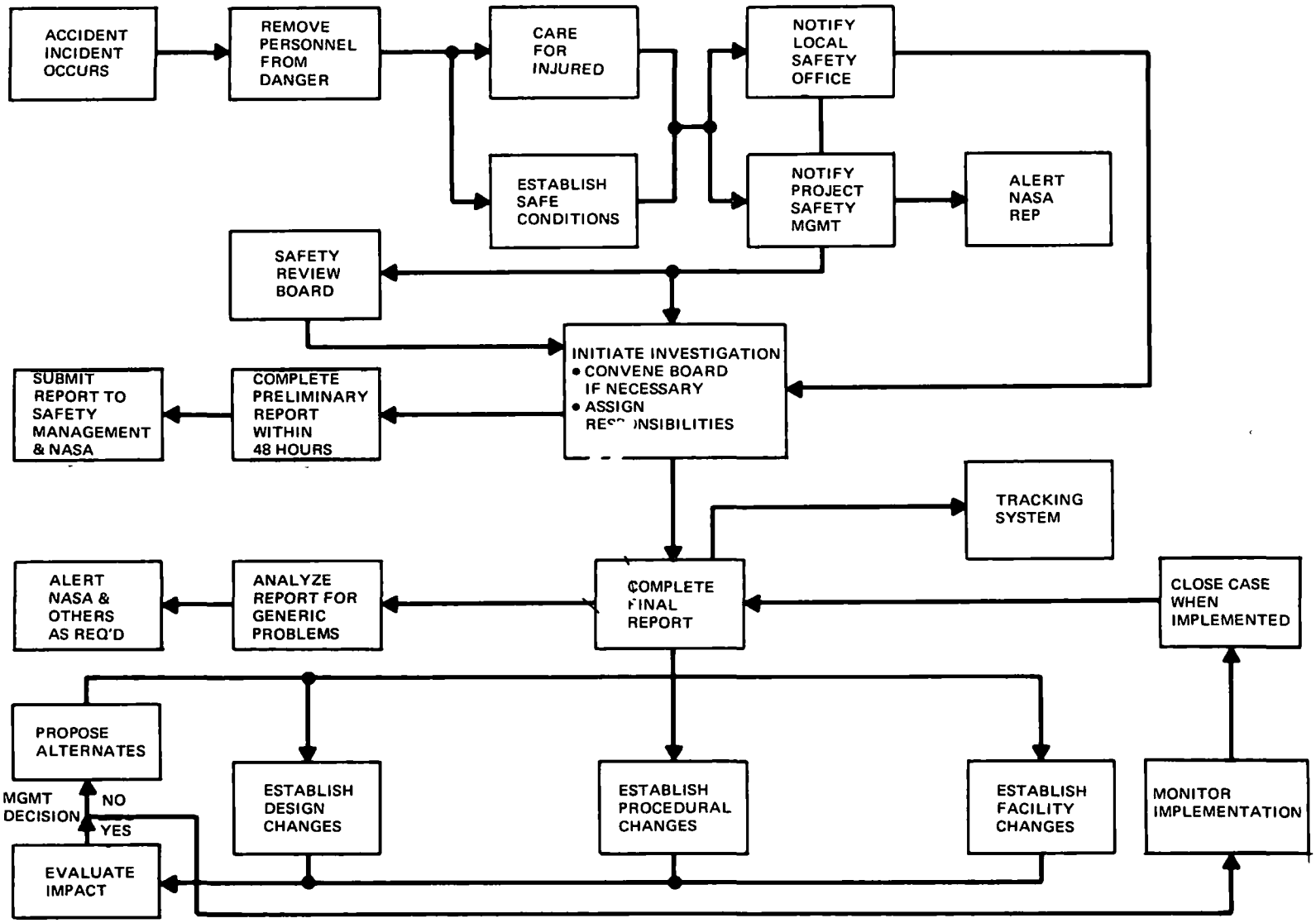

Fig. 2.3-4 Accident/Incident Control

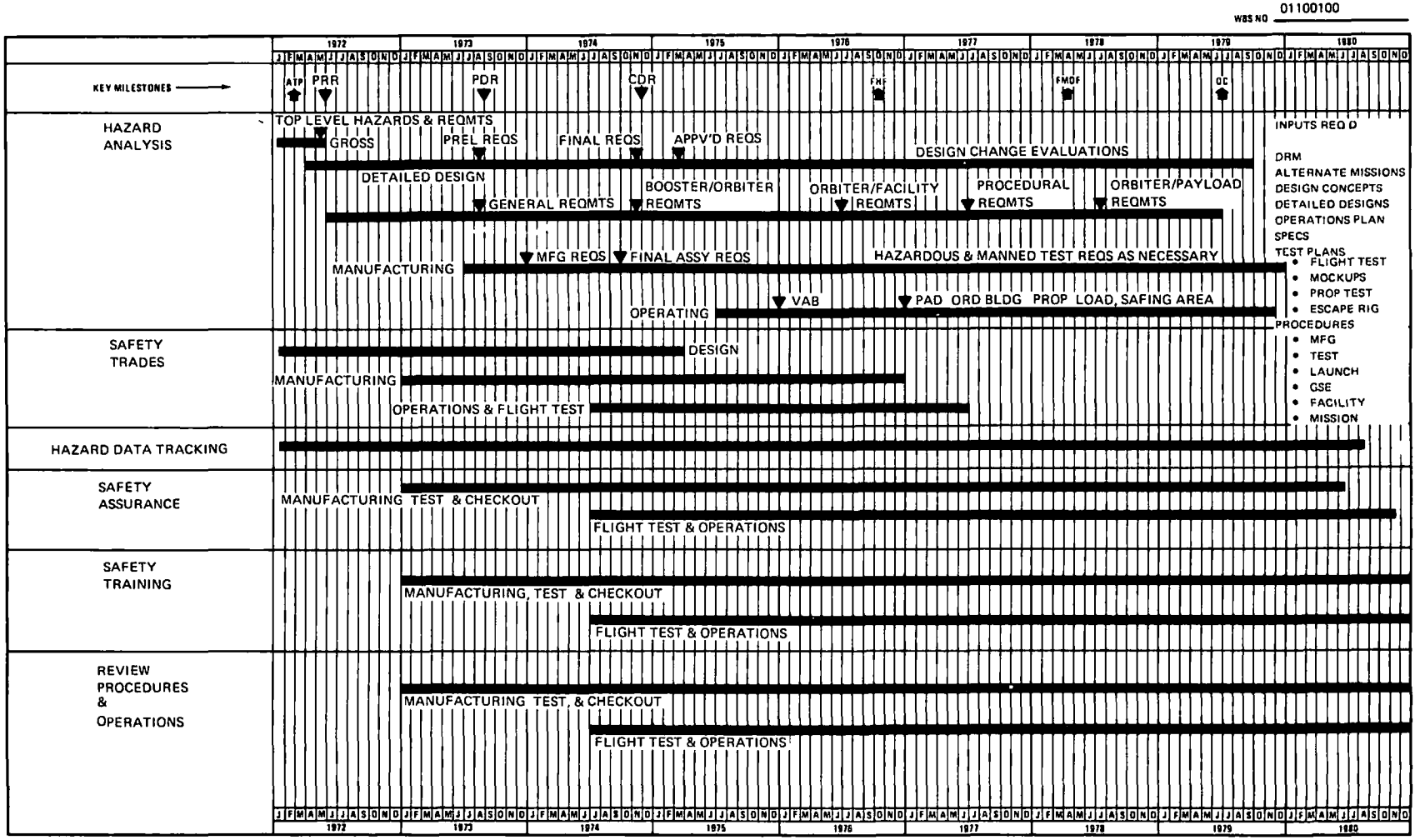

Fig. 2.3-5 Systems Analysis and Integration Safety Schedule

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TABLE 2.3-1 SAFETY CERTIFICATION REQUIREMENTS

Certification Requirements*	Method				Constraints			
	Test Unit	Flt Unit	Analysis	Simulation	1st Hor Flt	FMOF	OC	Comments
Crew/Passenger Egress								Assumes Facility
• Vertical (Launch Pad)				X				Verification Vehicle
• Horizontal (Landing)				X	X			
• Crew Emergency Egress (during development flight phase)								Refer to subsection 10.4
Fire Detection/ Extinguishment								
• Air Breather Engines				X	X			
• Cabin				X	X			
• Other fire Zones				X	X			
Propellant leak detection tion/safing								
• On-board		X		X	X			
• GSE	X				X			Facility Verification
• Facility		X			X			
EC/LSS Emerg Cabin	X	X		X	X[1]			[1]First flight is constrained only if the ferry flight envelope is exceeded.
APU Exhaust Control	X	X		X	X			
Wet Runway Stopping Distance		X					X	
Lightning Strike/Corona Protection	X			X		X	X	
External Tank Separation		X	X	X			X	

*Only those interfaces critical to safety are identified for certification

2.3.7 COMPUTER SUPPORT REQUIREMENTS

Hazards associated with all program elements must be tracked per NASA requirements. A data handling program that will allow rapid data access and standard format printout is required. The objectives of the program are discussed in The Safety Plan, No. 552-43-RP-8. It is anticipated that modification of an existing data handling program will satisfy the requirements for hazard tracking. Reports will be required four to six times per year and special analyses four times per year.

2.4 SYSTEMS ANALYSIS AND INTEGRATION

2.4.1 SYSTEMS ANALYSIS

Specific systems analysis activities described in this section are performed to define, control, and optimize the orbiter system requirements during the design and development phase. These activities improve upon our Apollo experience and are designed to ensure that design integrity is maintained while isolating, identifying, and correcting the areas of technical risk and difficulty at the earliest time.

The process will not be a serial type of activity that constrains the overall orbiter system design, but will be a logical, continuous, iterative process that studies and decides between alternatives on the basis of cost effectiveness and system performance. The process will also provide for the verification and traceability of the system and subsystem requirements in relation to the basic orbiter mission objectives.

The task networks for systems analysis is shown in Fig. 2.4-1.

2.4.1.1 Analytical Techniques

Mission analysis will be conducted in conjunction with NASA in a manner similar to the Apollo program. Parametric constraints defining the mission requirement limits within which the orbiter system must respond, will be identified in tradeoff studies and flow and timeline analyses. With these analyses we will study and identify the requirements imposed on the orbiter during all mission phases including those known critical requirement phases such as pad aborts, mated flight, max Q alpha, separation, ascent aborts, reentry and ferry.

To derive the necessary mission related requirements for allocation into subsystem requirements, the following techniques will be used:

- A design reference mission will be constructed to identify and baseline the relationship to the various parameters of interest
- Starting with a top-level mission flow, a continual functional breakdown of each mission phase will be conducted. Each successive mission phase level will identify those functional elements that must be satisfied by a subsystem

requirement. These elements will be described in a Systems Operational Data Book that will contain the ground rules, guidelines, assumptions and constraints necessary for generation and verification of the subsystem design requirements. This documentation will be a logical extension of the Systems Design Handbook generated during this present study

- Mission and operational planning support will be provided to NASA during the horizontal and vertical flight test program. The support will include the establishment, planning, and verification of the flight test objectives and requirements. The data obtained during these phases will be analyzed and documented to assist NASA in establishing the orbiter constraints, vehicle utilization and assessment of proposed mission changes, during the operational phase

A system functional analysis will be performed to analytically determine and verify the effectiveness of orbiter subsystem design criteria. This iterative process will be accomplished by performing trade studies and analysis on the baseline orbiter system/subsystem configuration requirements specified in the NASA orbiter CEI specification and/or identified as result of mission analysis.

System sensitivity models for each subsystem will be formulated to identify those parameters that are critical to the overall orbiter system performance. These critical parameters will then be analyzed for their effectiveness in performing their required function in the proposed orbiter design configuration. These sensitivity models will include a combination of functional flow diagrams, math models, and physical simulations.

An in-line segment of this analysis provides the necessary math models for developing the computer software required for simulating hardware during early integration simulation. This analysis also provides for the establishment and verification of test checkout requirements, signal tolerance and GSE requirements.

The off-line segments of this analysis will use sensitivity models for continuation of early trade studies. These trade studies will evaluate the interplay of subsystem configuration changes and orbiter system design requirements. These trade study analyses will continue through the development phase.

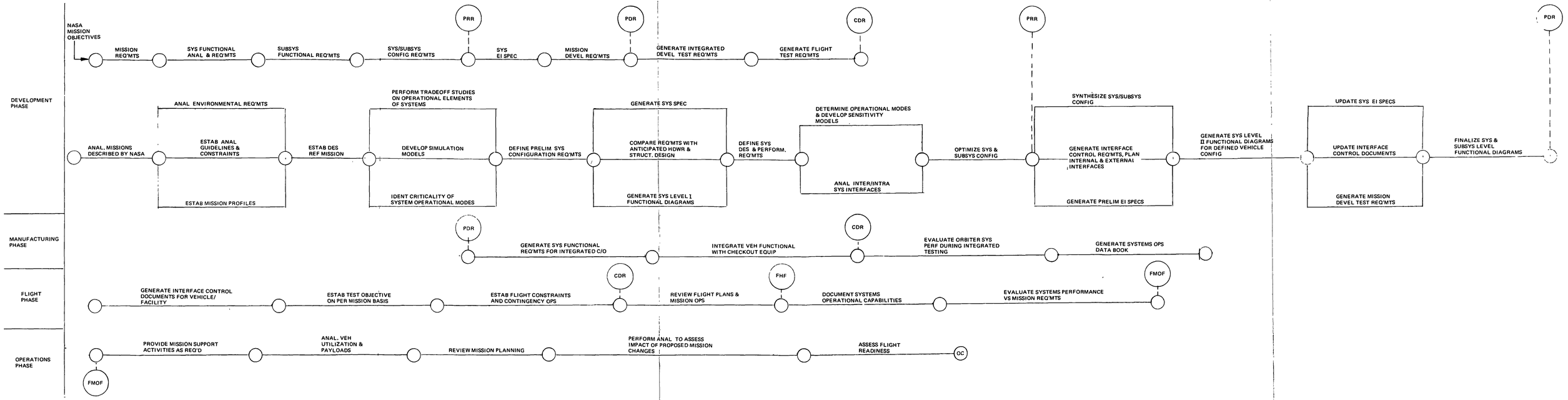

Fig. 2.4-1 Systems Analysis And Integration Logic Network

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2.4.1.2 Task Schedule

The task schedule for systems analysis effort during the engineering and development phase and its relationship to the overall program milestones is shown in Fig. 2.4-2.

2.4.1.3 Commonality Candidates

- Design Reference Mission Format
- System Operational Data Book
- System Trade Study Format
- Math Model Formats

2.4.1.4 Facility Requirements

None

2.4.1.5 Computer Support Requirements

- Math models using existing program format to support trade studies
- Mission simulation models to support orbiter systems operational analysis

2.4.2 SYSTEM INTEGRATION

The orbiter system demands an extensive and continuous systems engineering interface control effort to assure compatibility between the various system elements. The system integration tasks will identify, define, and control and intersystem and intrasystem interfaces involved in the orbiter design. Our experience gained during the Apollo program has shown that this activity requires constant monitoring and review to avoid misunderstandings and to allow for timely development of compatible system hardware and software. A comparable continuous effort will be required during orbiter system development.

The task networks for systems integration is in Fig. 2.4-1.

2.4.2.2 Analytical Techniques

System level functional diagrams will be generated, maintained, and controlled to identify the orbiter subsystem interface requirements. The diagrams will form a design integration baseline for the initial vertification of subsystem interface compatibility while providing integration requirements for the orbiter ground support equipment.

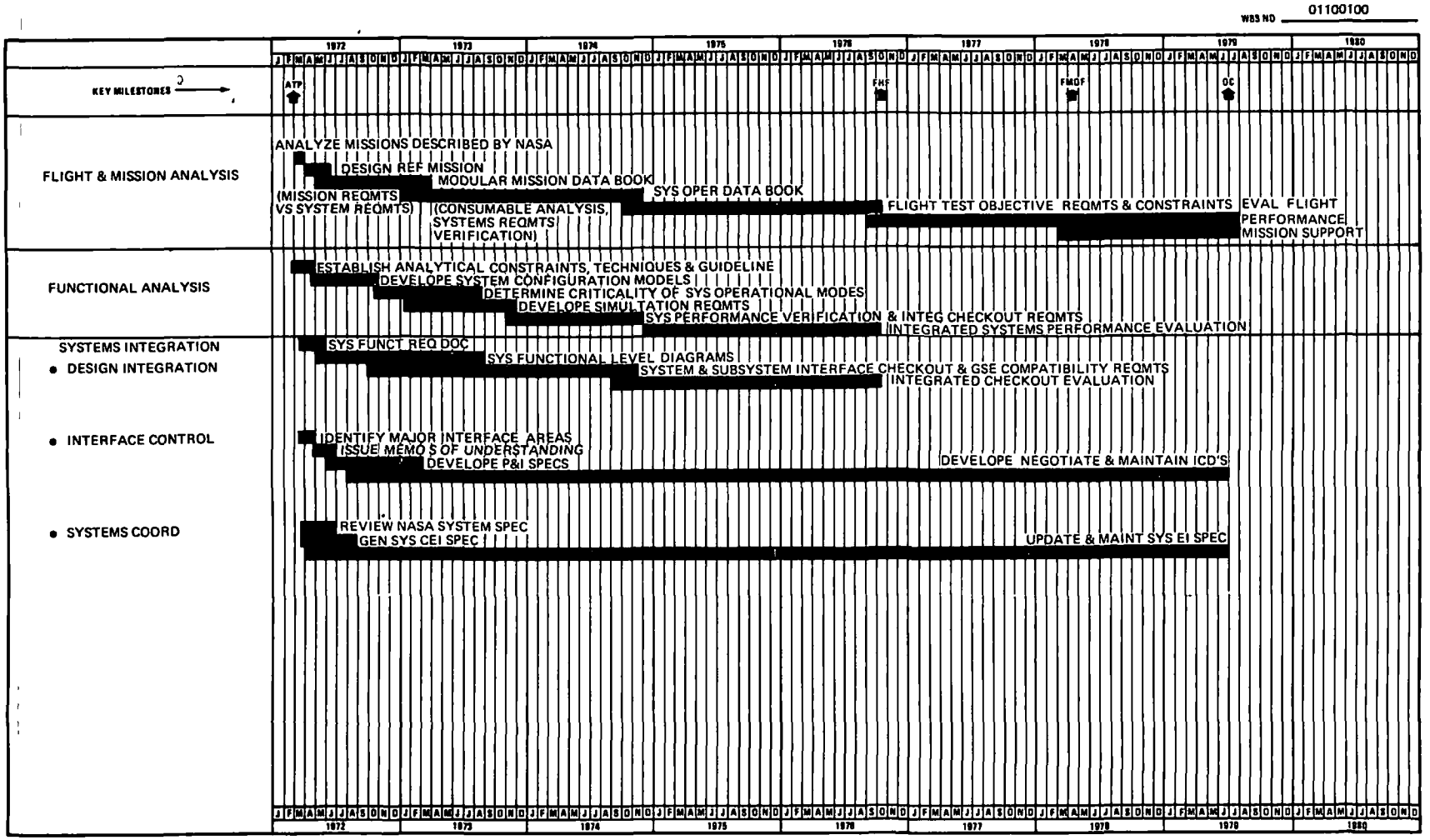

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Fig. 2.4-2 Systems Analysis And Integration Schedule

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An orbiter system specification will be prepared and maintained to establish the total orbiter system requirements and allocate these requirements to the various elements of the orbiter system. This task will insure compatibility between the orbiter system specification and the CEI specification. A strict change control procedure will be implemented to provide the required traceability from the orbiter system requirements and subsystem CEI specifications.

Interface Control Documents (ICD's) will be used to document and control the physical and functional interfaces between other program elements and the orbiter system (i.e. launch facilities, MSFN, satellites, etc.) and between elements of the shuttle system (i.e. orbiter/booster, orbiter/engine, orbiter/payload, etc.) These documents will be prepared, negotiated and controlled by interface control working groups whose members include representatives of the various orbiter system developers.

In view of the initial difficulties experienced in this area during the Apollo program the following items will receive early emphasis:

- Computer software interface requirements
- Physical interfaces to be mocked up and integrated into the orbiter test articles
- External electrical interfaces

2.4.2.3 Task Schedules

The task schedule for the system integration effort during the engineering and development phase and its relationship to the overall program milestone are shown in Fig. 2.4-2.

2.4.2.4 Commonality Candidates

- System Functional Diagram Formats
- Nomenclature Identification
- Systems Specification Format
- Interface Control Documentation Formats

2.4.2.5 Facility Requirements

None

2.4.2.6 Computer Support Requirements

- Data Bank Storage for ICD Status Reporting

2.5 CERTIFICATION PROGRAM

2.5.1 OVERALL POLICY

The certification program summarized in Fig. 2.5-1 will demonstrate, with high visibility and quick response, that the performance of the orbiter flight systems, ground support equipment and facilities conform with applicable design requirements. This certification program is an extension of the system developed for Apollo. It takes advantage of:

- Improved hardware and technology maturity
- Aircraft maintainability concepts
- Fail Op/Fail Safe redundancy
- Conventional aircraft incremental flight test approach

The certification program identifies the applicable certification requirements, determines the method by which certification will be accomplished, determines the constraints between certification requirements and establishes the date by which certification must be accomplished. Technical, cost and schedule factors are considered when determining the method for accomplishing certification.

When vehicle detail design has progressed to the point where the vehicle configuration and equipment schematics are available, initial certification requirements reviews (ICRR's) will be held. The preliminary certification requirements contained in Sections 2 through 7 will be baselined to appropriate specifications to assure that all functions are included and that changes are tracked. Specification requirements together with hardware performance criteria will be provided by the subsystem personnel who participate in this initial review. Reliability inputs at this time will consist primarily of historic data concerning similar equipment from other programs such as Apollo and airline operations. At this ICRR, the functions which are designated as certification requirements will be assigned a number from a master log and controlled until the certification requirement has been accomplished and a certification endorsement has been issued.

Final certification requirement reviews (FCRR's) will be held when the results from failure mode and effects analysis, weak link analysis, criticality analysis and environmental analysis are available from the reliability program. These data, together with the results of tests and other relevant data such as hardware maturity (new hardware; similar hardware from other NASA, DOD or commercial programs; hardware common to booster and orbiter) will be reviewed and the certification method finalized. Schedule risk, safety and crew confidence are qualitative factors which are also considered when finalizing the certification method. Certification methods include test, mathematical analysis, simulation, similarity and common usage. The results of the FCRR will be documented on the certification requirement form, Fig. 2.5-2 and submitted to NASA for review and approval. Upon NASA approval, the certification requirement will be either released to the appropriate analytical or simulation group or transmitted to the appropriate test organization as a firm test requirement. The certification group will monitor progress and publish periodic status report to the Grumman and NASA action centers. When the test/analysis is complete, a certification endorsement form, Fig. 2.5-3 will be submitted to NASA for review and approval.

The certification program will include both ground support equipment and facilities.

2.5.2 PRELIMINARY CERTIFICATION REQUIREMENTS

Certification requirements are indicated in Sections 2 through 7 for planning purposes only. These preliminary certification requirements provide the first inputs to the ICRR discussed in paragraph 2.5.1.

The certification requirements tables in this volume indicate the several methods of certification. The degree of confidence in the design and the nature of the potential problems were considerations when selecting the certification method. Where testing was determined to be necessary to support the analysis the options considered included ground test versus flight test, dedicated test hardware versus flight hardware, formal qualification versus development or proof tests, and component versus higher level of assembly tests. In each case the lower cost, second alternative was the approach selected where permitted by technical and schedule factors. The rationale for the method of certification will be documented initially on the certification requirement form. Deviations and changes to the method of certification as the program matures will be formally processed via certification change notification for NASA approval prior to implementation.

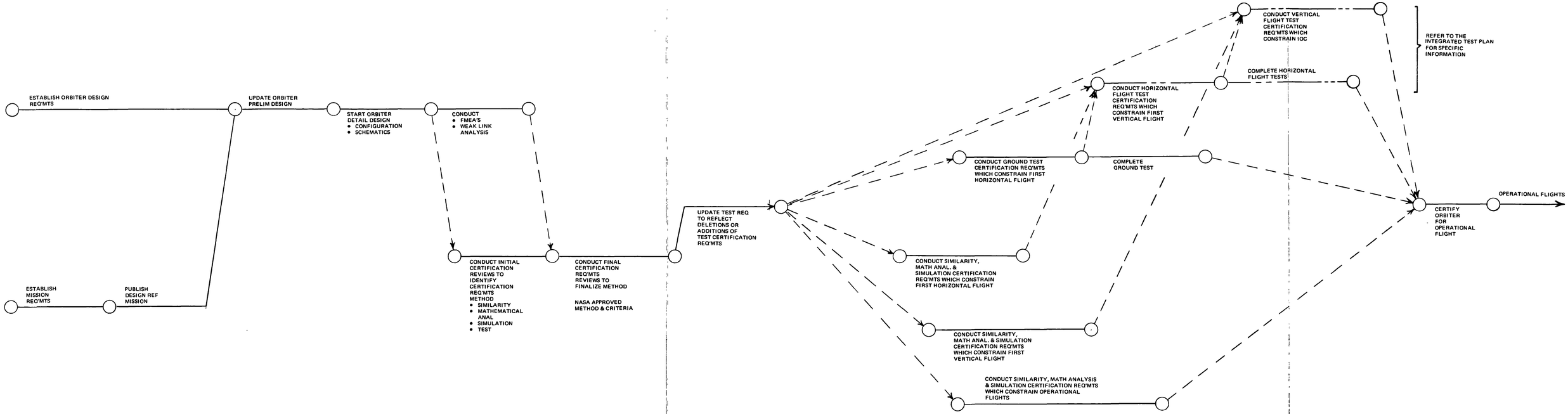

Fig. 2.5-1 Orbiter Certification Program Summary Logic

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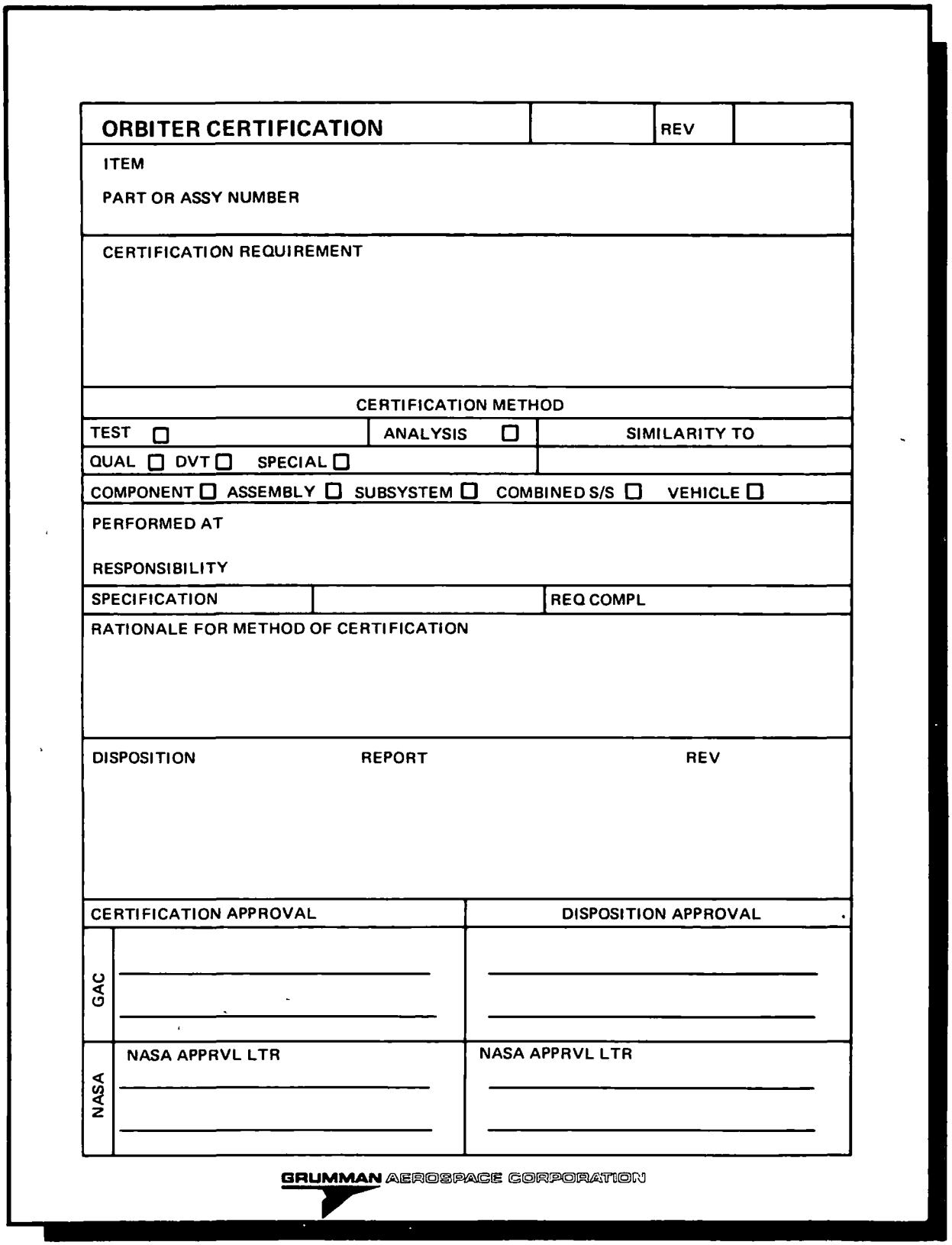

ORBITER CERTIFICATION | | REV |

ITEM

PART OR ASSY NUMBER

CERTIFICATION REQUIREMENT

CERTIFICATION METHOD

TEST ☐ | ANALYSIS ☐ | SIMILARITY TO

QUAL ☐ DVT ☐ SPECIAL ☐

COMPONENT ☐ ASSEMBLY ☐ SUBSYSTEM ☐ COMBINED S/S ☐ VEHICLE ☐

PERFORMED AT

RESPONSIBILITY

SPECIFICATION | | REQ COMPL

RATIONALE FOR METHOD OF CERTIFICATION

DISPOSITION | REPORT | REV

	CERTIFICATION APPROVAL	DISPOSITION APPROVAL
GAC	_____ _____	_____ _____
NASA	NASA APPRVL LTR _____ _____	NASA APPRVL LTR _____ _____

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Fig. 2.5-2 Certification Requirement Form

CERTIFICATION ENDORSEMENT FOR: OCR

THIS IS TO CERTIFY THAT

THE DESIGN OF THE FOLLOWING ITEMS IS ADEQUATE FOR FLIGHT ON THE INDICATED ORBITER FLIGHT

P/N	FLIGHT

TEST OR ANALYSIS DATA

- ITEM TESTED, PART NO
- TEST LOCATION
- TEST OR ANALYSIS START & COMPLETION DATES
- FINAL REPORT

DIFFERENCES BETWEEN ARTICLE TESTED & FLIGHT ARTICLE

DISCUSSION:

(SIGNATURE) _____
GAC COGNIZANT ENGINEER

(SIGNATURE) _____
GAC SYS/SUBSYS ENGINEER

ENCLOSURES

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Fig. 2.5-3 Certification Endorsement Form

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Factors influencing the choice of "non-test" as the method of certification include:

- Criticality - potential problems will not jeopardize crew safety or primary mission performance
- Demonstrated reliability - test/operational experience with similar equipment
- Redundancy

The "non-test" methods of certification indicated on the CR tables are defined as follows:

- Mathematical Analysis - An evaluation of the ability of the hardware to meet the environmental/performance levels of a specified mission using data from other sources; i.e., other test results, operational data and engineering analysis and data
- Simulation - The use of simulators to prove hardware performance under dynamic flight conditions
- Similarity - Requires that the following conditions be met:
  - Design differences between the item being certified and the previously certified item are insignificant
  - The similar, previously certified item was designed for and certified to equal or higher environmental stress levels and time duration than those anticipated for the item being certified
  - The item being certified was fabricated by the same manufacturer as the similar item using the same processes, materials and quality control
- Common Usage - Any identical unit certified for flight use on a space program (booster hardware). The identical unit must have met the applicable certification criteria

The levels of assembly shown on the CR tables are defined as follows:

- Component - The smallest grouping of parts that perform a single elementary function within an assembly

- Assembly - An arrangement of subassemblies, components and parts performing one or more functions. (A subassembly is the smallest grouping of components that can be physically separated from the assembly)
- Subsystem - A major integral part of a system representing the first level of a functional breakdown below the total system level
- Combined Subsystems - Includes two or more subsystems
- Flight Vehicle - Complete flight structure and all electrical, mechanical and fluid subsystems installed therein

2.6 CHECKOUT REQUIREMENTS & CRITERIA

2.6.1 TASK DESCRIPTION

Systems Engineering will develop the specification of checkout requirements and criteria for the development, ground checkout, flight test and operational phases of the program. This approach provides early assessment and control of design as well as projecting the total test program requirements. This projection is necessary to evaluate the progress of vehicle design and support equipment development, which ensures checkout compatibility and complete confidence in the end product quality.

The checkout requirements matrix will be developed to define requirements for:

- Development test planning
- Ground and flight test planning
- Identification of support equipment requirements
- Establishment of software interface control

The test tolerance budget development will identify the expected environment adjustment for ground checkout, the required support equipment accuracy and identify the need for development of new test techniques. New test techniques will provide flexibility in developing checkout interfaces and the lack of suitable checkout equipment or need for expensive support equipment modifications. In addition, this type of budgeting provides the perspective of OBC parameters and analytical models.

Analysis of trend data will provide a means of identifying servicing and maintenance requirements on hardware prior to the hardware malfunction becoming critical. This is accomplished by careful selection of critical functional parameters measured during development and production, and maintaining an accurate history of components both on a generic and piece part level. Statistical methods will be applied to project future operational life which will provide minimum downtimes to reduce operational flight interruptions.

A system of controlled inputs will be used to establish Onboard Checkout (OBC) requirements for ground and flight checkout. This will assure optimum use of data recording for flight and trend data analysis.

A program of malfunction and fault isolation analysis will be used to assure that all needed test points and support equipment interfaces are available as well as eliminating unnecessary duplication. This analysis will determine the best means of detecting hardware malfunctions and the simplest method of fault isolation.

Documentation control will be used to assure that authorized test requirements and criteria are available for use by test organizations. Test plans and procedures will be reviewed and approved by engineering prior to implementation and the test results will be reviewed for satisfactory completion of test objectives. A system of change control will be used to permit changes of requirements, plans or procedures when required. The relationship of test requirements and criteria with contract specifications, test procedures and plans is shown in Fig. 2.6-1.

2.6.2 ANALYTICAL TECHNIQUES

Analytical techniques will be applied to checkout criteria definition and trend evaluation. Checkout criteria will be defined by combining statistical analysis of random and systematic uncertainties with rationale defined by flight requirements and appropriate environmental considerations. Math models of all test functional paths will be used to represent each path. The models will include:

- Support equipment inaccuracies
- Flight hardware uncertainties
- Special test equipment inaccuracy

which are random quantities and

- Environmental adjustments
- Aging and drift characteristics
- Identified off-nominal mean

which are systematic contributions. Random quantities will be root-sum-squared (RSS) and the systematic contributions will be algebraically summed to determine the total uncertainty of each path. This uncertainty will be subtracted from the mission boundaries of

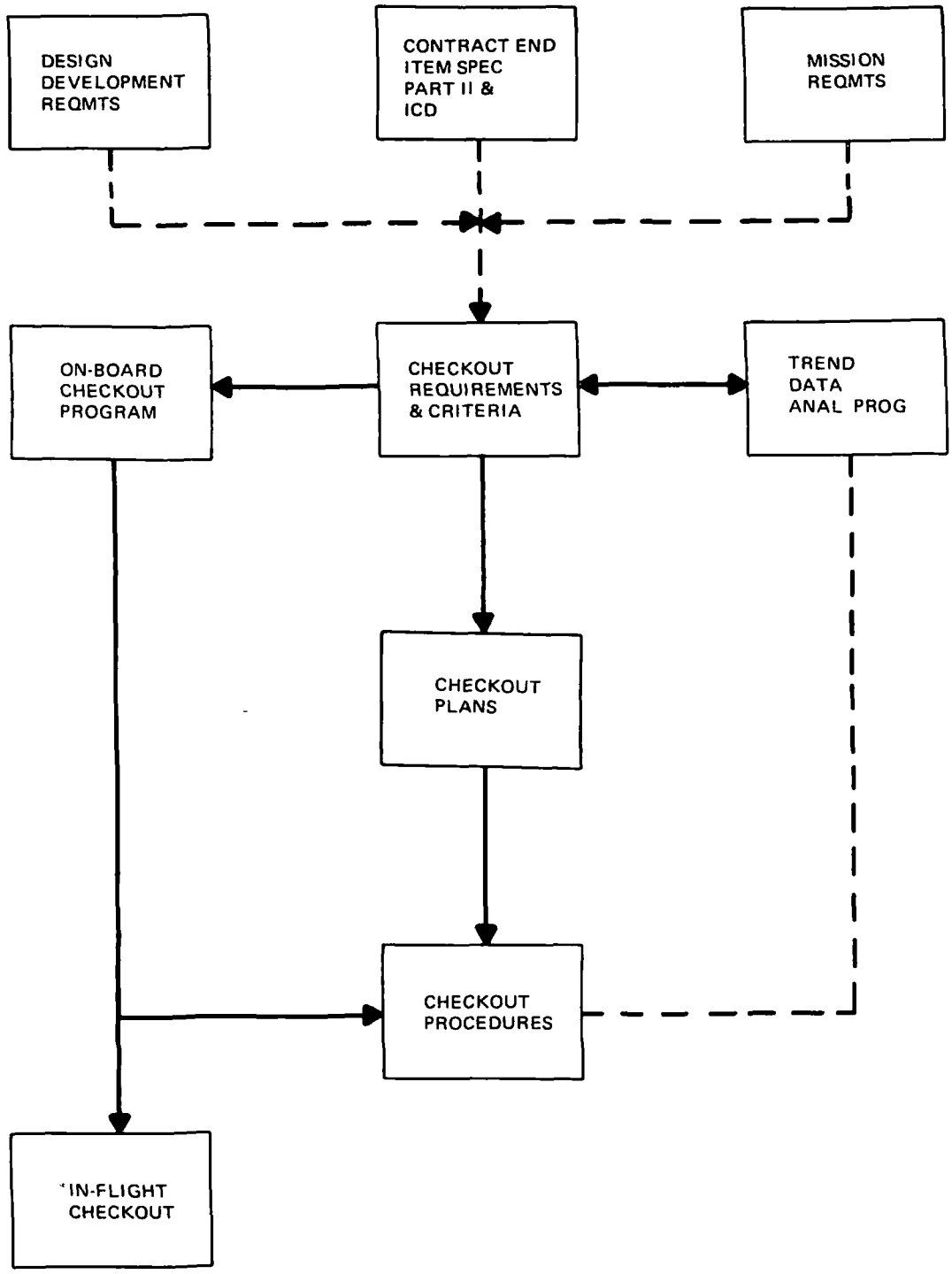

Fig. 2.6-1 Test Documentation Tree

functional operation to provide a checkout tolerance which will provide the best probability of detecting malfunctioning equipment

Trend evaluation will use data processing techniques to evaluate the hardware operational distribution with the goal of providing identification of aging and drift characteristics as well as "built-in" values. This is done by entering controlled test results and conditions of vehicle hardware into a data evaluation program which will provide statistical distribution for standard atmospheric conditions and for expected extremes of environment. These results will be compared to budgets used in checkout criteria and the checkout criteria will be updated.

2.6.3 COMPUTER SUPPORT REQUIREMENTS

The trend data analysis program will require computer support for statistical routines to provide hardware test data and population distribution, systems response probability and the hardware degradation and operational life expectancy.

Onboard Checkout programs will require computer support to determine OBC test and evaluation routines for systems integration, ground and flight test, and operational pre-flight and in-flight programs in conjunction with flight hardware development.

Software programming is required as follows:

- Trend data analysis statistical routines
  - Hardware test data population distribution
  - Flight vehicle systems response probability per vehicle
  - Hardware degradation and life expectancy
- Onboard checkout program development
  - Systems integration
  - Horizontal pre-flight checkout
  - Horizontal flight checkout
  - GVS systems status
  - Vertical pre-flight and flight checkout
  - Operational pre-flight and in-flight checkout
  - Systems status survey
  - Malfunction isolation

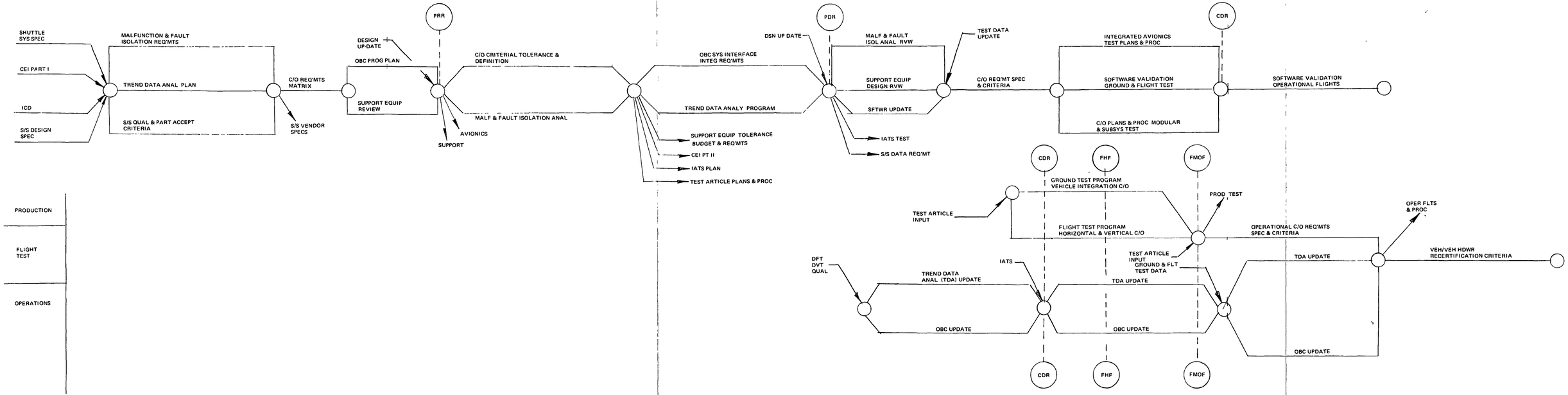

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Fig. 2.6-2 Checkout Requirements and Criteria Logic Network

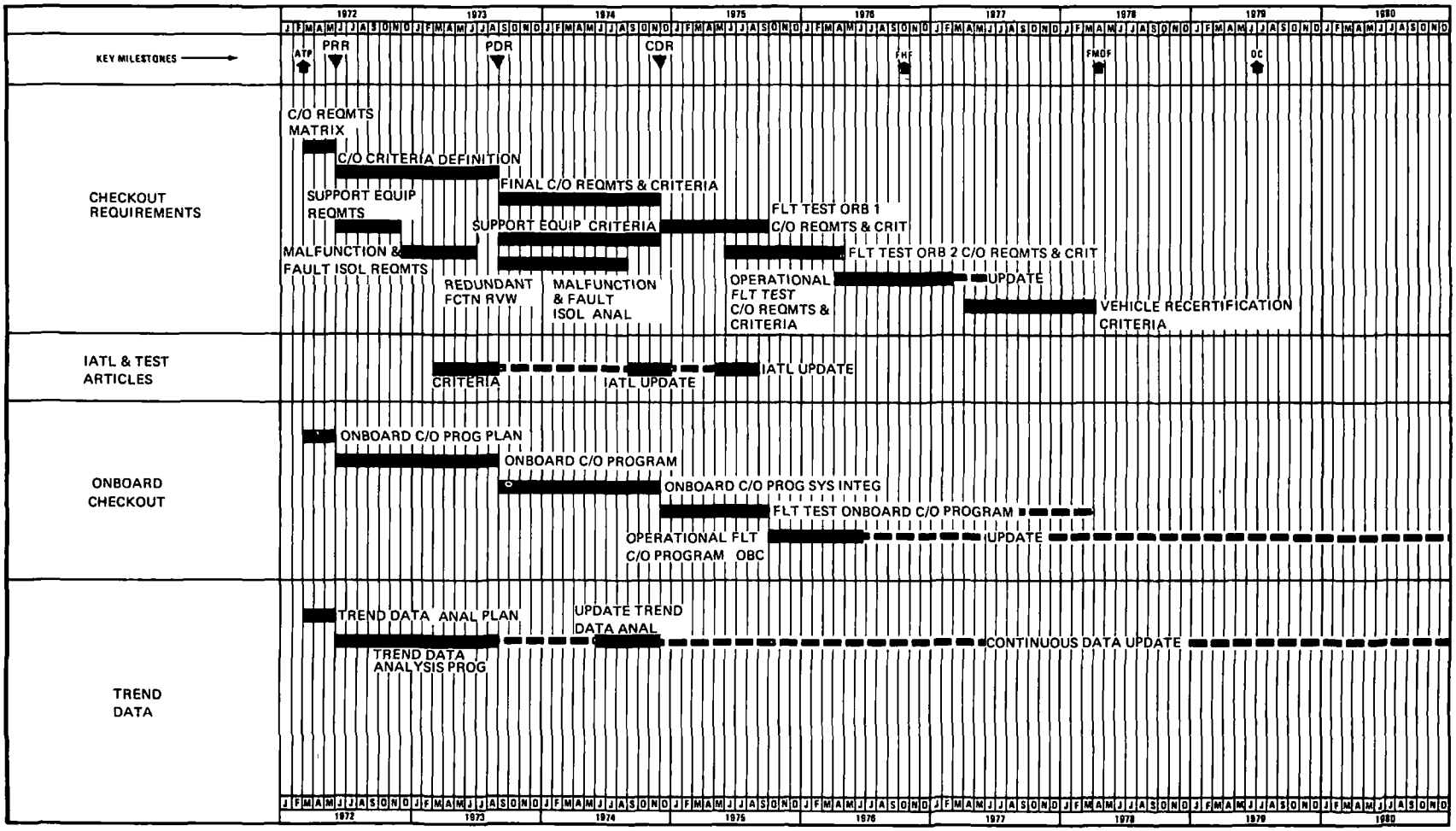

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Fig. 2.6-3 Systems Analysis and Integration Checkout Requirements and Criteria Schedule

TABLE 2.6-1 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

Item	Common	Common Potential	Not Common	Remarks
Trend Data Analysis Program		X		Booster could use the same software to check hardware statistical population and potential degradation

2.7 CREW SYSTEMS

2.7.1 TASK DESCRIPTION

Crew systems engineering generates crew information requirements and human engineering design requirements and verifies subsystem design to ensure effective integration of the flight crew, passengers and ground support personnel into the space shuttle system design.

Functional analyses are performed to develop flight crew task allocations and preliminary crew information requirements. From these analyses, control and display requirements, crew station functional design and crew task sequences and workloads are being developed.

Human engineering design requirements, in accordance with MIL-STD-1472A, will be established for the flight crew station and passenger areas for the orbiter, and for orbiter support personnel ground equipment. Special emphasis in the generation of human engineering design requirements for the flight crew station and passenger areas will be devoted to vertical launch, orbital operations and entry. Because the orbiter passengers include male and female scientists who vary widely in age and physical conditioning, existing anthropometric and physiological data will have limited applicability. The impact of launch loads and zero g operations on the wide crew/passenger spectrum will be investigated

Functional requirements and human engineering design criteria and recommendations will also be provided for crew and passenger related equipments and considerations These include mobility and restraint systems, control of interior cabin and external acoustical noise levels, toxic, noxious and hazardous environmental limits both inside the orbiter and during pre-launch operations, orbiter habitability including on-orbit food preparation and waste management, acceleration limitations and control, recommended emergency escape provisions, resolving visibility and lighting problems, EVA operations and cargo handling.

Full scale mockups will be constructed and used to assess and verify cabin interior design features and arrangements and to evaluate flight crew procedures. The provisions and procedures required for crew and passenger emergency pad egress, flight crew external

visibility and payload deployment and retrieval, and other critical man-machine operational interfaces will be evaluated through the use of mockups. The complete mockup program for verification of crew/equipment interfaces including crew compartment stowage reviews (CCSR), fit tests (C^2F^2), zero gravity (KC-135) and neutral buoyancy tests and their scheduling is presented in paragraph 10.1.1. Crew systems personnel have had considerable design review and evaluation experience via mockup activities and KC-135 flights on the LM program and will participate in the generation and verification of human engineering design requirements and orbiter flight personnel procedures via one g and zero g testing.

The adequacy of flight crew/subsystem interfaces and crew operational procedures/techniques for critical orbiter mission phases such as docking, entry and landing will be evaluated in a simulated mission environment through dynamic simulations. Simulator descriptions and schedules are contained in subsections 2.14, 10.1 and 10.6. Piloted simulation studies, including a human factors evaluation of candidate display and control subsystem designs, will be used to investigate the crew's role in the orbiter system so that full advantage of the human component may be factored into vehicle design. Use of crew systems personnel for the development of crew procedures and the evaluation of crew performance using simulation results was effective in the LM man-machine integration.

In addition to conducting dynamic simulations, crew systems personnel will aslo conduct studies in a facility not requiring orbiter vehicle dynamics, primarily to evaluate specific vehicle design problems in relation to man's sensory, perceptual and motor capabilities.

Grumman will apply human performance and physiological data gathered from these simulation and mockup activities, as well as from the LM, high performance aircraft and deep submersible programs to the orbiter design. Data obtained from other manned spaceflight (Mercury, Gemini, Skylab), ground-based laboratory programs, centrifuge and zero g testing will also be used. Where such data is not available or applicable, appropriate performance and physiological tests will be initiated or recommended to NASA.

Preliminary training requirements analysis has identified the need for a dynamic moving base trainer with full orbiter mission simulation capability. This will be an update of the LMS at MSC. Since docking and landing are particularly critical mission phases, a

part-task trainer capable of flying those phases may also be required. Further evaluation of orbiter operations and applications of appropriate tradeoffs may result in the recommendation of a second full capability trainer in lieu of the part-task trainer. The requirements for a dynamic procedures trainer as well as for specialized zero g training facilities such as KC-135, and neutral buoyancy at a NASA facility will be specified in detail and provided as inputs to the training program plan (see logistics and maintenance plan). Accomodation and operations training requirements will also be included in this training program plan. Human engineering design requirements for the orbiter trainer cabin configuration and instructor consoles will be generated as the orbiter design proceeds beyond preliminary design review (PDR).

To ensure an acceptable man-machine interface, the following parameters will be certified prior to flight:

- Orbiter cabin gaseous trace contaminants - resulting from non-metallic material outgassing
- Orbiter cabin atmospheric particulate matter contaminants - resulting from LiOH dust concentration or other vehicle hardware The use of materials will be controlled and verified on the horizontal flight test vehicle
- Orbiter cabin noise levels, effective temperature and N_2, O_2 and CO_2 partial pressure - The ECS/LSS integrated test rig will be used for certification
- Waste Management System - Certification of functional design will be by qualitative, subjective acceptance during vendor qualification tests
- Potable water - Certification will be achieved by performance of microbiological and chemical laboratory analysis on stored fuel cell water and by subjective taste of the drinking water
- Orbiter Lighting - Will be certified by subjective and objective lighting reviews to ensure quality and uniformity of cabin lighting

2.7.2 ANALYTICAL TECHNIQUES

The primary analytical techniques used by crew systems personnel are the application of quantitative methods, experimental design, and statistical evaluation to the performance of man in the vehicle system.

A computer program will be used in compiling crew procedural sequences. For this purpose, either a crew scheduling program already developed by Grumman or one of the available NASA programs (such as the Langley Space Station Mission Simulation Mathematical Model) will be used.

Two other Grumman developed programs, both of which are operational, will also be used. They are the Shuttle Crew Compartment Atmospheric Gaseous Trace Contaminant Control program, and a comprehensive statistical program, titled Analysis.

2.7.3 COMMONALITY CANDIDATES

- Crew station layout
- Control and display design
- Caution and Warning system philosoply and design
- Instrument panel nomenclature
- Flight personnel pad egress
- Visibility from the cockpit

2.7.4 FACILITY REQUIREMENTS

Crew Systems personnel will make use of the mockup and simulation facilities described in this document in subsection 10.1. A Human Engineering work area will be used to obtain quick-reaction human engineering data where the use of more costly simulation facilities is not warranted.

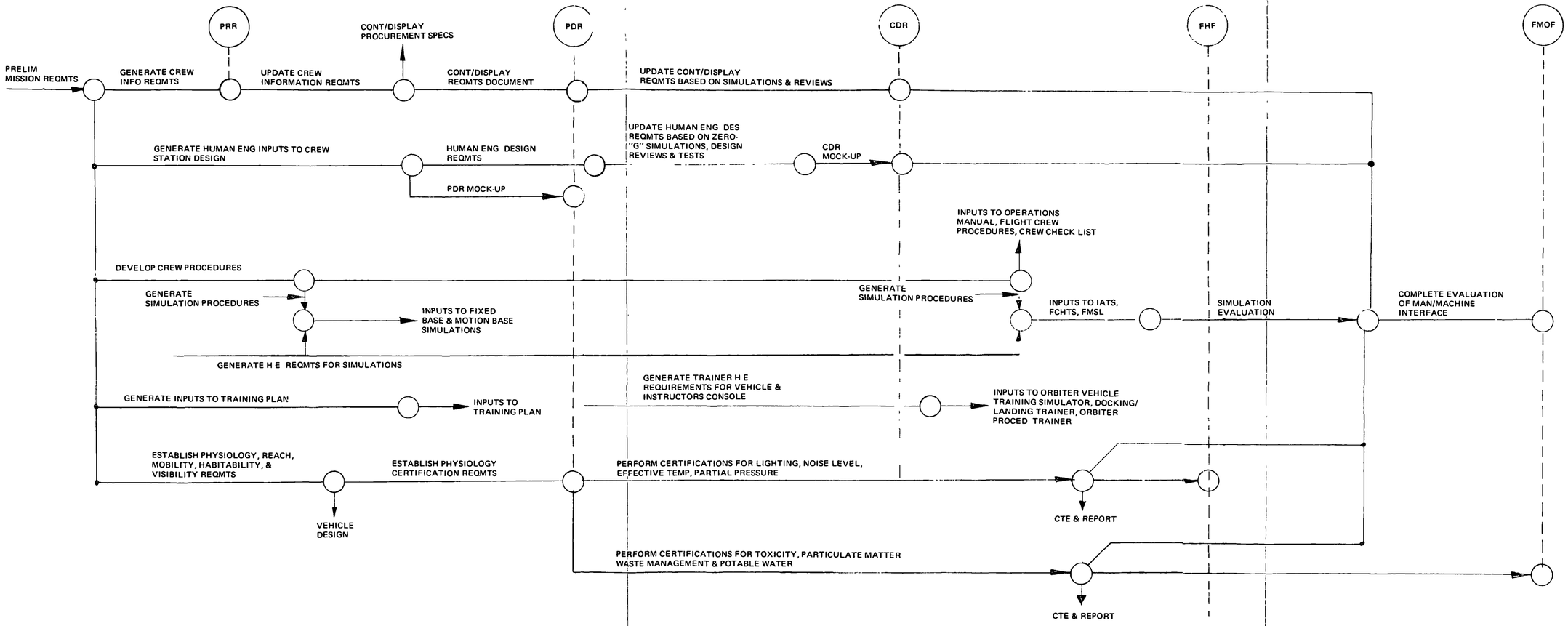

Fig. 2.7-1 Crew Systems Logic Network

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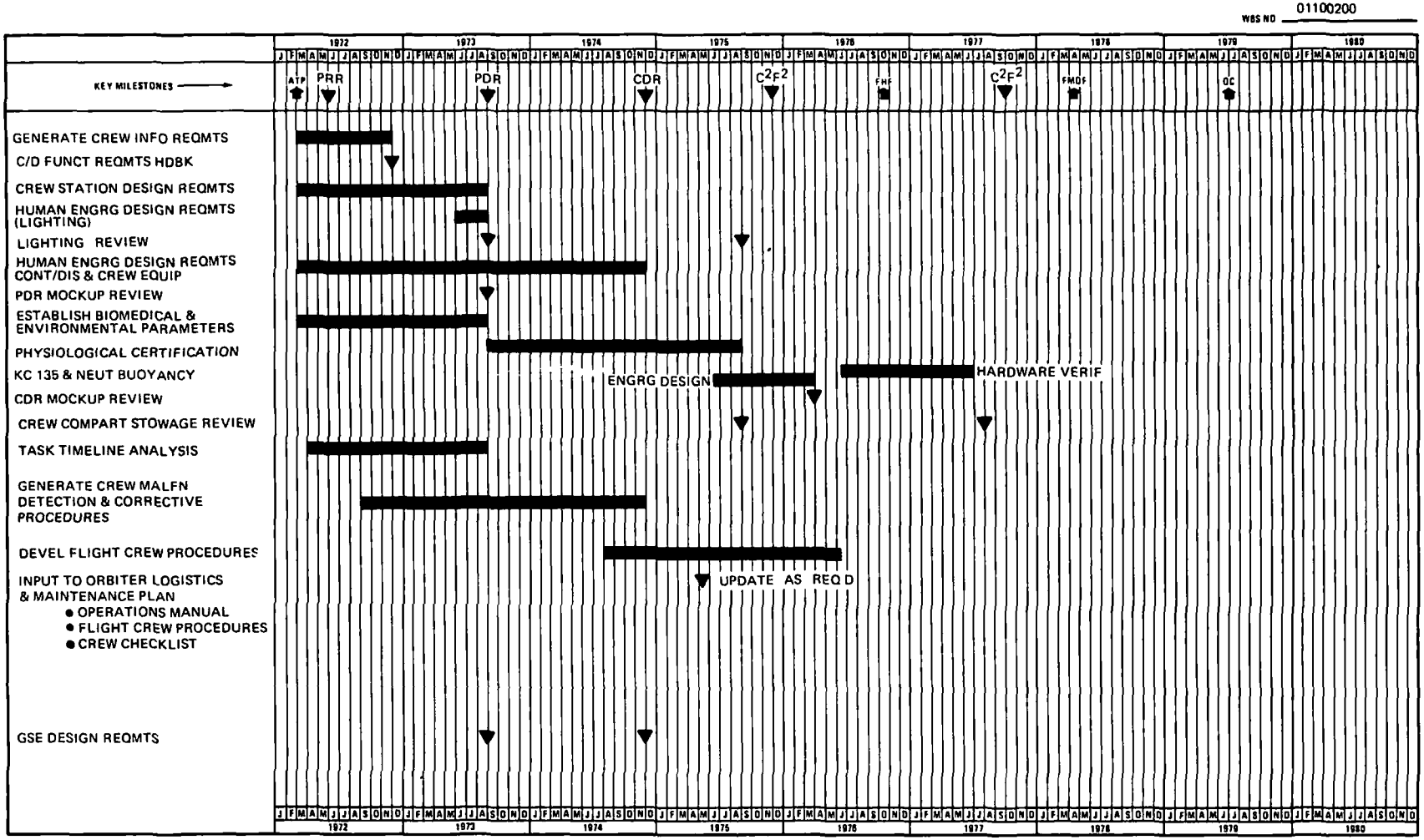

Fig. 2.7-2 Crew Systems Schedule (Sheet 1 of 2)

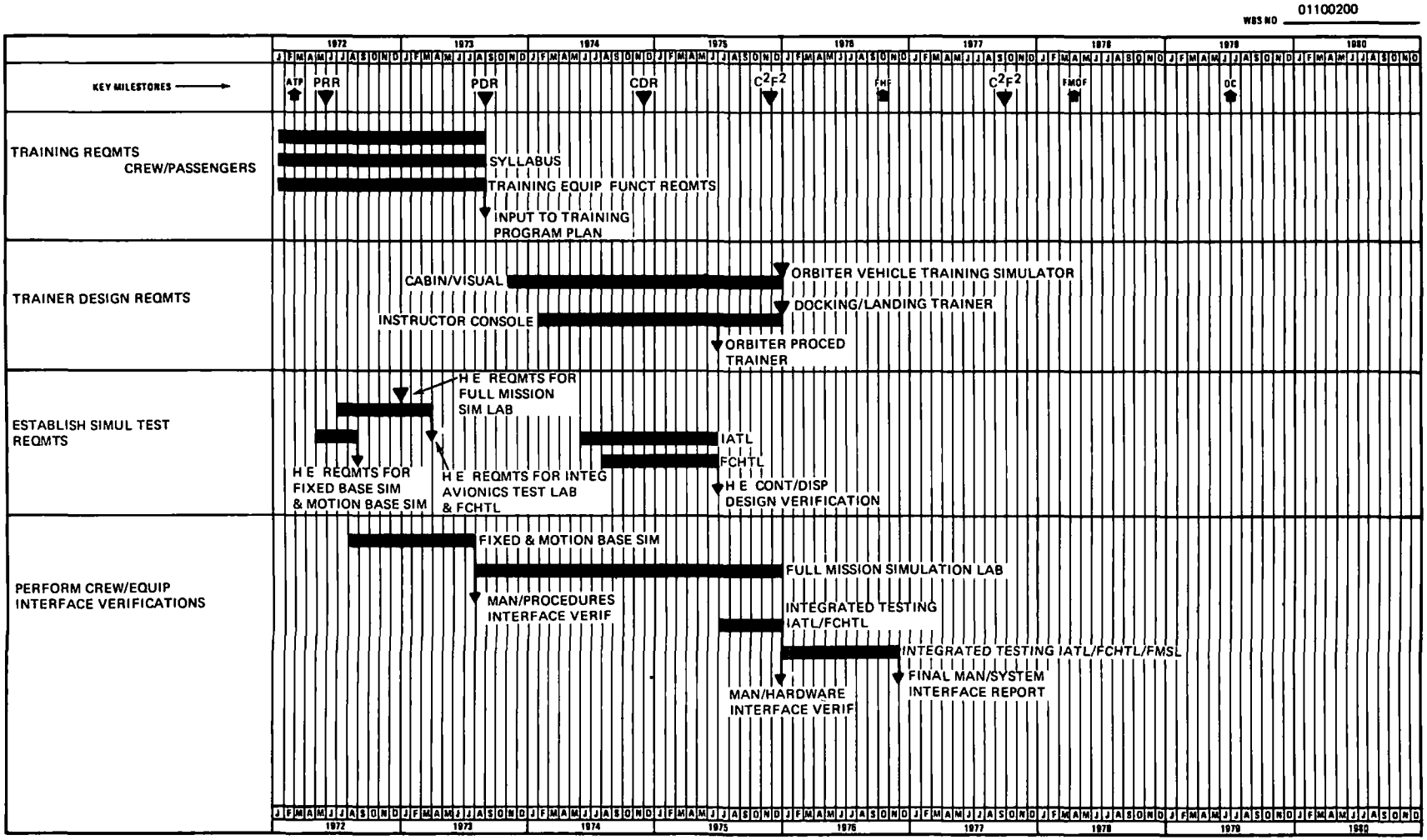

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Fig. 2.7-2 Crew Systems Schedule (Sheet 2 of 2)

2.8 AERODYNAMICS

2.8.1 TASK DESCRIPTION

Aerodynamics phase C/D tasks are to:

- Establish methods and criteria needed to assure orbiter atmospheric flying qualities, stability and control, and performance requirements
- Translate vehicle performance and flying qualities requirements into vehicle shape and control system requirements
- Determine orbiter aerodynamic configuration necessary to provide specified vehicle launch, ferry and landing performance and stability and control characteristics using theoretical, empirical and experimental methods as appropriate
- Determine vehicle control system requirements for artificial feel systems, control surface actuators, autopilot control loops
- Maintain liaison with appropriate hardware design groups, and monitor aerodynamic and control system configurations to ensure vehicle performance capability

These tasks will be apportioned and performed for significant orbiter operational phases to permit early tradeoffs to assure a safe, low cost system with the greatest mission capability. The phases which will be investigated are:

- Initial configuration definition
  - Tail-High speed directional stability
  - Wing - Landing performance and high angle of attack trim capability
  - Engine (Air Breather) - Landing waveoff requirements and go around capability
  - Controls - trim corridor capability, dynamic stability requirements, and minimum fuel consumption
- Abort and tank separation
  - Booster orbiter separation envelope to establish initial conditions for orbiter tank separation analysis
  - 6 DOF orbiter/tank separation analysis - Abort modes and resulting tank/orbiter abort envelope

- Spin analyses
  - Orbiter spin resistance and sensitivity analyses and spin wind tunnel test
  - Spin prevention system definition
  - Spin recovery mode requirements
- Reentry and landing phase - Performance and flying qualities
  - Establish reentry corridor
  - Apportion RCS/aero surface control blending
  - Establish cross ranging capability and footprint
  - Landing distance and waveoff capability
  - Flying qualities studies to provide requirements for automatic/manual landing system, control surface actuator, autopilot, stability augmentation system
- Ferry
  - Performance studies to establish air breathing engine requirements and satisfy range, takeoff, landing including engine failure analysis and FAA requirements
  - Flying qualities analysis - dynamic response characteristics, controllability, coupled motions, short period characteristics
  - Strap on propulsion system studies
  - Autopilot, stability augmentation and automatic landing system studies

An integrated approach to the solution of these critical areas will be performed using analyses supported by wind tunnel testing and the use of extensive simulation facilities.

The wind tunnel testing proposed for the orbiter and described in subsection 2.20 uses Grumman and NASA test facilities where possible. Special purpose tests such as captive trajectory of the booster/orbiter and orbiter/tank separations are currently planned to be performed at Air Force or private facilities.

Wind tunnel testing provides a major tool in establishing the vehicle configuration and verifying analytical estimates. These tests will provide vehicle force and moment data, interference flow field analysis, spin analyses, inlet and nozzle interference characteristics, power effects, and booster/orbiter, orbiter/tank separation simulation through the use of captive trajectory tests. The logic network is prepared to

allow for reiteration of these results into succeeding analyses and tests which finally conclude with a series of flight vehicle documentation tests allowing the development of the required certification report and manual.

The simulation program utilizing fixed/moving base simulators and the Cornell Aero Lab Inflight Simulator (TIFS) will verify the man-in-the-loop operation of the shuttle. Flying quality parameters will be assessed and control system design objectives judged. Typical flight path control maneuvers will be made to determine pilot Harper-Cooper ratings. Failure modes of operation will be assessed in terms of the pilot's ability to control and meet mission objectives after the failure. The landing phase of the mission will receive critical attention in terms of glide slope control, flare and go-around maneuvers. The simulator will also serve as a pilot familiarization tool and will allow for appropriate inputs prior to first flight.

2.8.2 ANALYTICAL TECHNIQUES

2.8.2.1 Math Models

Each of the programs listed in paragraph 2.8.2.2 which calculate aerodynamic characteristics include a math model of the vehicle geometry or includes provisions to tie into the master dimension system programs, Section 3. Those programs which compute vehicle trajectory or response characteristics include math models of the vehicle dynamics. Similarly, the control system algorithms are included in the math models of these analysis and synthesis programs.

2.8.2.2 Computer Programs

Grumman uses the SADSAC data processing and analysis programs. In addition, several Grumman developed programs are used for vehicle and control system design and analyses for attainment of flying qualities and performance goals. These are listed as follows:

Program Name	Program Description
Aerodynamic Characteristics	
• Stage Separation Aerodynamics	— Interference C_n & C_m prediction during stage separation

Program Name	Program Description
Aerodynamic Characteristics (Cont.)	
• Hypersonic Aerodynamic Prediction Program	Predicts hypersonic viscous aerodynamic charateristics of arbitarily oriented vertically symmetric shapes. Surface pressures, local loads, and over 50 aero parameters available
• Lifting Surface Program	Computes pressure, lift, and load distribution for a given wing planform, mean camber surface & twist distribution
• Airfoil Sect. Press Dist and Aero Characteristics	An exact method for calculating local velocity and pressure at the surface of, & aerodynamic coefficients for, any general airfoils section; based upon potential flow techniques
• Mean Camber Surface Program	Computes the mean camber surface required for a given loading
• Compressible Turbulent Boundary Layer	Integral moment of momentum and momentum equations are used to provide boundary layer properties of momentum thickness, form factor, local skin friction coeffient, and Nusselt number with heat transfer. Good for compressible subsonic and supersonic flows
• Neumann Subsonic Airfoil Program	Potential flow solution of direct problem of as many as eight separate airfoil sections simultaneously
Performance	
• Takeoff and Landing	Determine balanced field length for FAA takeoff & landing. Includes effect of wet runway conditions
• Dive	Transition from reentry mode to cruise in equilibrium flight
• Long Trim Program	Trim parameters using non-linear wind tunnel data δ_e, δ/g, α/g, N_p
• Ground Run Takeoff	General ground-run takeoff study including pilots action
• 6 DOF Entry Time History	Complete entry from orbit to touchdown with non-linear aerodynamics & full autopilot

Program Name	Program Description
Performance (Cont)	
• TOPLV (Trajectory Optimization for Lifting Vehicles)	Two & three dimensional flight path optimization of advanced aircraft such as minimum time to climb, minimum time to accelerate and minimum turns
• Low Speed Performance Program	Computes power-on trimmed lift coefficient level flight acceleration & instantaneous rate of climb for input values of ambient temp, altitude, gross thrust factor, center of gravity position
• Two DOF Pop-Up	Purpose to calculate minimum approach speed ($V_{pa_{min}}$) from the pop-up maneuver (a 50 ft vertical altitude change in 5 sec from the initial glide slope.)
• Time, Fuel & Distance to Climb	This program solves for time, fuel and distance consumed during climb to a given altitude (or ceiling) for a prescribed flight path
• Energy Maneuverability	The program also uses the Rutowski method for determination of minimum time & minimum fuel climb paths to a given altitude & also computes the corresponding time, fuel, & distance consumed
• Dive Pull-Out Maneuver	The dive program determines the flight path & time & fuel consumed during a constant angle dive from a given set of entry conditions
• Level Flight Accel & Turn	The acceleration program computes level flight acceleration or deceleration & the corresponding time, distance, & fuel consumed
• General Performance	The principal output items are maximum specific range, endurance fuel flow, maximum rate of climb (lg steady state) & maximum speed.
Flying Qualities	
• GE Mass Separation	Space shuttle separation and trajectory study
• 6 DOF Trajectory Analysis	Six degrees of freedom equations of motion - stability axis data input - includes all primary control system equations

Program Name	Program Description
Flying Qualities (Cont)	
• Tank Trajectory - 6 DOF	Computes the 6 DOF trajectory of a tank separated from a spacecraft
• Longitudinal Point Stability	Roots of characteristic equation, frequency, damping n_z/α , transfer functions
• Flight Path Stability	Determines capability of holding flight path
• Nosewheel Liftoff	Determines nosewheel liftoff speed
• Lateral Dir Point Stability	Roots of characteristic equation, frequency, damping ϕ/β, ϕ/V_e transfer function
• Adverse Yaw & Rolling	Determine sideslip and performance rolls from trim in 4 DOF program
• 5 DOF Rolling Performance	Ties in control system design and aero surface size to meet rolling performance requirement
• Dynamic Derivative Program	Computes dynamic derivatives from static & geometric data
• SDAT	Static derivative axis transformation
• DDAT	Dynamic derivative axis transformation
• 3 DOF Long. Time History	Non-linear entry in the vertical plane. Simplified version of 6 DOF program for extensive in-depth studies
• DATCOM Program	Computes static subsonic aero derivatives from geometry using USAF DATCOM methods
• 5 DOF Program	Incorporates aircraft flight control system equations which are solved in conjunction with the equations of motion to determine the response of the aircraft to several maneuvers at constant forward velocity
• Aircraft Spin Dynamics	Six DOF math model of the aircraft dynamic motion tailored to explore & analyse the spin characteristics

Program Name	Program Description
Flying Qualities (Cont)	
• 3 DOF Long. Time History	Uses lift, drag and pitching moment equations to determine aircraft response to control deflections
• One Engine Minimum Control Speed Analysis	Calculates the C_L and rudder deflection needed to maintain 5° of bank
Control Systems	
• 3 DOF Long. Point Stability	Linear program that generates transfer function, root locus and frequency response data
• 3 DOF Lat-Dir Time History	Lat-Dir version of 3 DOF long. program
• 3 DOF Lat-Dir Point Stability	Lat-Dir version of 3 DOF long. program with multi-loop feedbacks
• Long-Point Stab. with Flex Fuselage	Determine interaction of control system & fuselage flexibility
• Nose Wheel Shimmy	Program computes the time history of response of nose gear swivel motion to initial disturbance. Includes shimmy damper equation & certain non-linearities such as Coulomb friction and dead zone
• OPBS Specific Linear Optimal Control Optimization Problem	Employs the Davidon-Fletcher-Powell descent algorithm with scaling (Rossi) on the cost functions of a constrained feedback structure (Jameson, Rossi) using the solution of the standard eigen-value - eigenvector problem (Nolan) as suggested by Rossi
• OPA5-PP Control System Optimization via Algebraic Solution of the Riccati Equation	Employs the algebraic solution of the matrix Riccati Equation via the standard eigenvalue - eigenvector problem (LATENT)
• OPC1 Least Squares Model Referenee	Can be used to describe the automatic control system to cause one vehicle (plant) to have a response which always duplicates that of another similar vehicle (plant)

Program Name	Program Description
Control Systems (Cont)	
• R1-SP Least Squares Pole Matching	Limited to single input systems. Will choose values for an allowed subset of state of feedbacks which minimize a weighted sums of differences between a desired set of poles & the actual poles
• OPA4-SP/PP Standard Linear Optimal Control Problem (Kalman)	Employs numerical integration of the matrix Riccati differential equation via the 4th order Runge-Kutta (MAGIC)

TABLE 2.8-1 SYSTEM CERTIFICATION REQUIREMENTS

Certification Requirement	Certification Method		
	Analysis	Model Test	Flight Test
1. Horizontal flt config, perf & flying qualities certification, SAS reqmts	•	•	•
2. Launch abort envelopes - hydro tank separation envelopes & characteristics	•	•	•
3. Spin recovery characteristics - spin recovery & prevention procedures - definition of spin recovery devices	•	•	•
4. Orbiter approach & landing control system definition, landing piloting techniques & flying qualities	•	•	•
5. Orbiter reentry cross range characteristics, RCS/aero blending, reentry operational procedures	•	•	•
6. Orbiter SAS reqmts for FMOF	•	•	•

TABLE 2.8.2 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

Item	Common	Potential Common	Not Common	Remarks
Launch Configuration Wind Tunnel Testing		•		Potential of using similar if not identical models from the individual orbiter & booster tests & use them in either a launch configuration or separation wind tunnel test
Separation Testing		•		
Autopilot and Control System Mechanization		•		

TABLE 2.8-3 FACILITY REQUIREMENTS LIST

Title & Description	New	Exist	Contr	Govt
Grumman Facilities				
7 x 10 ft Low Speed Tunnel		•	•	
26 in. Transonic Tunnel		•	•	
15 in. Supersonic Tunnel		•	•	
36 in. Hypersonic Tunnel		•	•	
NASA Facilities				
Langley				
8 ft Transonic Tunnel		•		•
16 ft Transonic Tunnel		•		•
4 ft Unitary (high and low speed legs)		•		•
31 in. Hypersonic Continuous Tunnel		•		•
24 in. Hypersonic Variable Density Tunnel		•		•
Spin Tunnel		•		•
Ames				
6 ft Transonic/Supersonic Tunnel		•		•
11 ft Transonic Tunnel		•		•
12 ft Transonic /Subsonic (Pressure Tunnel)		•		•
9 x 7 ft Supersonic Tunnel		•		•
14 ft Transonic Tunnel		•		•
3 1/2 ft Hypersonic Tunnel		•		•

TABLE 2.8-3 FACILITY REQUIREMENTS LIST (Cont.)

Title & Description	New	Exist.	Contr	Govt
Airforce Facilities				
AEDC				
16 ft Transonic Tunnel		●		●
16 ft Supersonic Tunnel		●		●
Private Facilities				
4 ft LTV Transonic/Supersonic Facility		●		

TABLE 2.8-4 REQUIREMENTS LIST

Title & Description		New	Exist.	Contr	Govt
Interface Requirements with Systems					
1. Full mission Simulation Laboratory	See Systems Simulation Subsection 2.14 & 10.6	X		X	
2. Fixed Base Simulator				X	X
3. Moving Base Simulator (Handling Qualities)		X		X	X
4. Flight Controls Hydraulic Test Stand		X		X	
5. Total In-Flight Simulator (TIFS)			X	X	

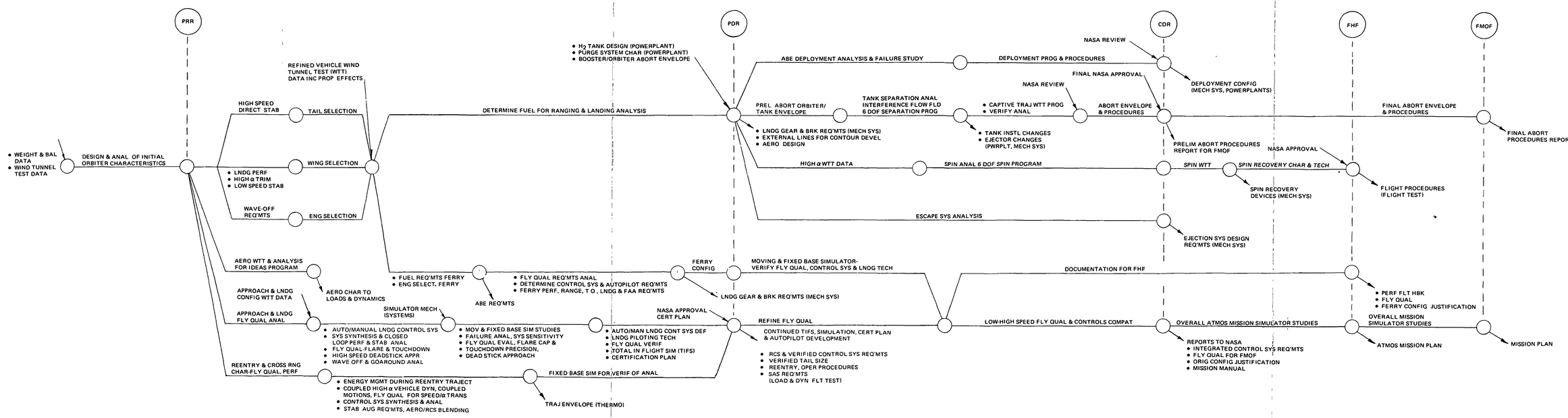

Fig. 2.8-1 Aerodynamics Logic Network

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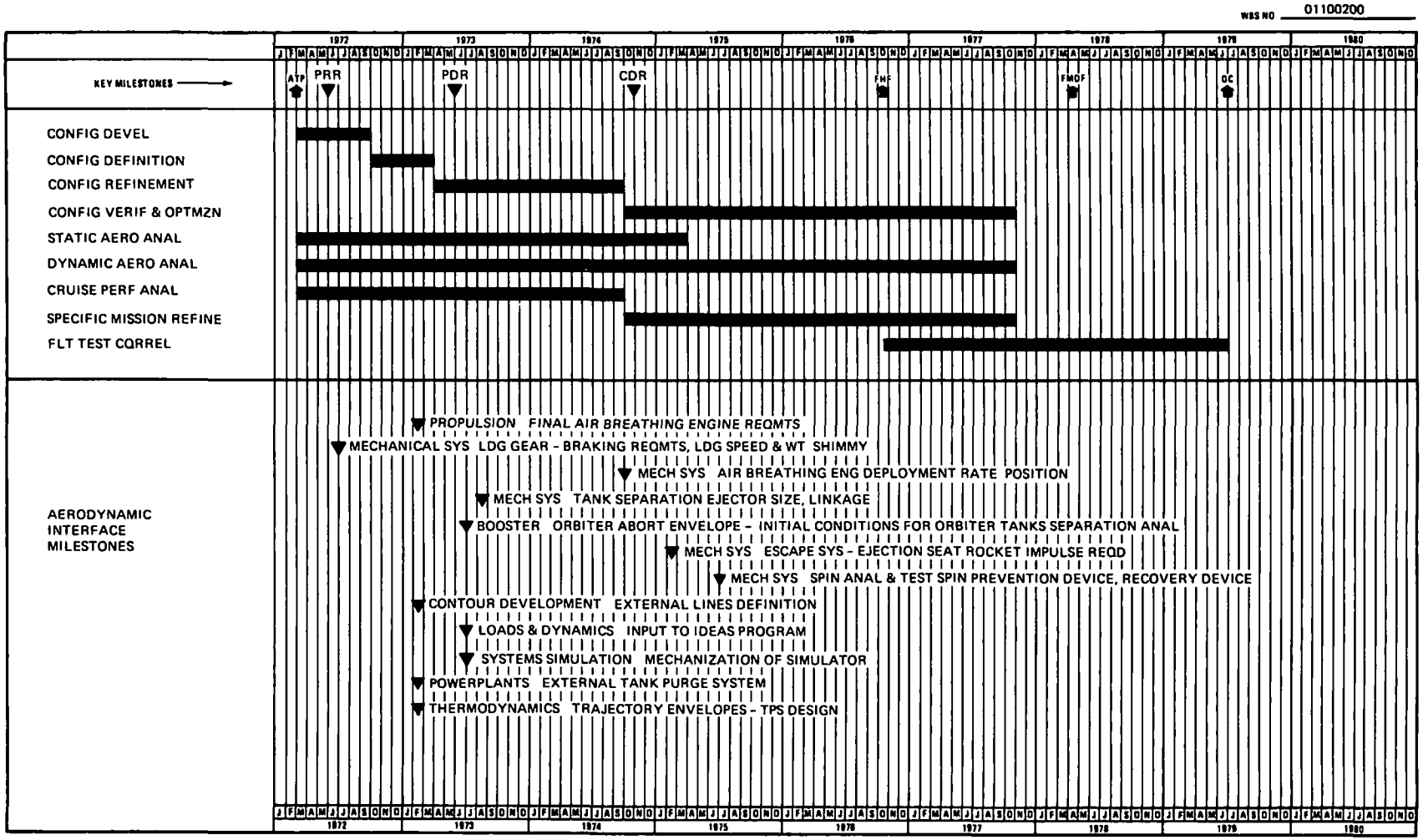

Fig. 2.8-2 Vehicle Design Analysis/Aerodynamics Schedule

2.9 STRUCTURAL ANALYSIS

2.9.1 TASK DESCRIPTION

The primary task of the Structural Analysis Group is to assure that the orbiter is structurally adequate for crew safety and mission success. This task will be carried out in close coordination with interfacing in-house groups, other shuttle system elements and NASA.

Key areas requiring concentrated effort are:

- Achieving a light weight, cost effective structure for the design environments and requirements
- Structural math models (for both internal loads and dynamic analysis)
- Thermal-structural combined loads
- Load, temperature, time and cycling effects
- Fracture control (stress corrosion, fatigue, fracture mechanics)
- Pressurized vessels (tanks, crew compartments, etc.)
- Composites utilization (boron epoxy, boron polyimide and boron aluminum structural forms)

The groups comprising the Structural Analysis Section are:

- Structural Analysis (Basic Structure)
  - Thermal and loads stress analyses, deflections and stiffness
  - Fatigue life prediction analyses
  - Detail member strength analyses
  - Mathematical models

- Mechanical Systems Structural Analysis
- Equipment and Installation Structural Analysis
- Complex Redundant Structural Analysis

The Structural Analysis Section will also consider the following areas in selecting configurations and materials:

- Cost
- Weight and performance
- Producibility, maintainability, relability etc.

2.9.1.1 Task Summary

- Establish design criteria, critical design conditions, load envelopes, temperatures and thermal gradients, time - temperature - load histories for creep and fatigue evaluation, fracture mechanics control
- Review, approve and update structural ICD's
- Select optimum basic structural configurations and materials
- Perform detail analyses to predict adequate structural integrity and satisfy life requirements
- Establish materials and structural component development test requirements
- Establish major component structural test requirements, support tests and evaluate results
- Support the vehicle fabrication and transportation
- Establish structural limits for mission operations document
- Support all mission operations
- Evaluate all mission structural data measurements. If different than design data, reevaluate structural integrity. Evaluate any structural anomalies occurring in mission

- Provide support for seller operations
- Submit detail documentation for strength and life of the vehicle
- Coordinate closely through SMD/MSC on all phases of the above task summary

2.9.1.2 Task Approach

A detail structural design criteria document will be prepared specifying all the critical phases of the missions to be analyzed in detail for deflection determination of forces, temperatures, deflection stiffness requirements, and load and temperature cycle requirements. (See Fig. 2.9-1.)

Based on the design requirements, and with data supplied by the Design, Thermodynamics, Weights and Loads and Dynamics Sections, the Structures Section will idealize the primary structure and major secondary structural components to provide an accurate mathematical model which can be used for dynamic analyses and static/dynamic aeroelastic calculations. Effects of temperatures and gradients will be included in these studies. Local member loads and thermal gradients will be obtained from these data.

Structural interface control documentation must be approved (and partially generated) by Structural Analysis. Such effort includes the cross-flow of information, re: structural influence coefficients, structural deflections, structural loads, and structural temperature between Grumman and other contractors whether they be prime or sub. Such data will be revised and updated periodically.

The materials and structural element configurations will be selected for mechanical loads, temperatures, life and stiffness requirements, and deformations with cost and producibility as well as strength as a criteria. These elements will include stiffened and unstiffened plates, stiffeners, spar caps and webs, cylinders, and piping.

The detail stress analyses will include mechanical load and thermal stresses induced either by thermal gradients or materials differences. The thermal stress analyses will consider the effects of discontinuities in structural components as well as large thermal gradients as exists at the wing - fuselage intersections. Temperature-time histories through the members will be used to evaluate the critical gradients for thermal stresses.

The buckling of plate elements will consider applied forces and thermal gradients thru the thickness; where critical the fatigue of elements will consider thermal as well as load cycles for the life of the vehicle. Creep buckling will also be investigated and included in element life evaluation. All critical structural components will be checked for creep deformation, including creep recovery, to maintain the deformation limit requirements over the total life. Where critical, member attachments will consider the effects of temperature as well as mechanical loads.

In evaluation of fatigue life, materials data will be established by tests and analyses. Static and cyclic tests will also be conducted at selected critical load and temperatures to obtain S-N curves for fatigue life prediction. These tests will include notched specimens, mechanical joint elements and welded elements. A fatigue spectrum will be established and will include critical loadings as well as thermal cycles. The structure will be evaluated for stress corrosion cracking. Every effort will be made in the design and analysis phases to prevent residual stresses induced by fabrication and installation materials will be selected with high thresholds. Members will be analyzed for stress corrosion cracking where residual stresses are unavoidable. Past experience in this area has demonstrated that this problem area can be avoided or controlled without loss of structural integrity.

Structural test requirements will be established to demonstrate the adequacy of the basic vehicle as well as components. The test elements selection will be influenced by facilities and cost limitions in addition to demonstrating the adequacy of the component or major system. For large scale structural components and full system level tests, analysis and element evaluation tests will be conducted with a view to compressing the time of mission profile for high temperature fatigue testing.

Structural testing at any level will be supported by Structural Analysis in the forms of witnessing tests, assisting during test procedure, and evaluation of results.

Structural Analysis will support the groups responsible for handling and shipping through liaison with shop personnel, determination of "hard points" for handling, and provision of shipping constraints. Interface definition documents will be developed, reviewed and approved. Engineering procedural instructions to the shop will be generated and distributed. Shipping constraints, such as tankage pressure requirements, structural support point definition etc. will also be defined.

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Support effort during the fabrication of all shuttle vehicles will be provided. This includes shop liaison and MRB action review and approval. In addition, the approval of certain parameters relating to NDE procedures or pressure vessel proof testing as pertains to shop safety will be required.

Flight restrictions and operation data documentation will be defined by Structural Analysis. Included in this effort is the definition of minimum parameters for contingency or emergency operational conditions involving structural integrity.

Structural analysis shall support the efforts of sellers as follows:

- Establish the structural design requirements for inclusion in specifications of seller items. Included here is the review of seller design and analysis and the provision of technical assistance and direction during the course of the design and development program
- Establish the requirements for the testing of seller supplied items. This effort includes the witnessing of seller conducted tests as well as the evaluation and interpretation of test results

Telemetered structural data and that structural information which is recorded on board during flight test phases will be evaluated and used to verify the structure.

Formal technical documentation will be prepared and published. Included in this documentation are bi-weekly program review notes, monthly progress reports and study summary reports for the CDR and PDR's. The major portion of the task will be the preparation of load and analysis reports that will describe the structural design conditions and stress analyses of the shuttle and various ground test vehicles. These reports contain member load distribution for the various design conditions, stress analyses of the critical members and the definition of structural influence coefficients of shuttle structure. Close liaison will be maintained with SMD/MSC on all phases of the structural requirements, design, analyses, problems and related areas.

2.9.1.3 Fracture Control Summary

The fracture control plan delineates the approach to fracture control for main propellant tanks and other critical structures. It covers the following items:

- Proof testing
- Leakage detection, NDE
- Structural advantages of fracture control
- Fracture control during material procuring, fabrication, assembly, test and service history

Included will be results of fracture mechanics calculations for the H-33/H-32 orbiter. The above areas are covered in detail in paragraph 8.4.1.3 of the Technical Summary, Volume II. A review of the fracture control plan chart, Fig. 2.9-4, shows the distinct advantages of using the single mission LH_2 tanks and the removable LOX tanks. These advantages in summary are:

- The LH_2 single mission tanks can be designed using fracture mechanics with proof testing and NDE to give a high confidence level for crew safety. The experience gained in the Apollo program demonstrated the reliability of this approach
- The removable LOX tank configuration provides a similar high confidence in that after every mission the tank structure is checked by NDE methods. If required, it can be removed for refurbishment while an acceptance tested tank is installed for the next mission

2.9.2 ANALYTICAL TECHNIQUES

The analytical computer programs currently available for performing in-depth studies by the Structural Analysis Group include both programs within the IDEAS system (Integrated Design and Analysis System) and separate programs that cover special topics such as fracture mechanics. IDEAS is a management system for the integrated use of many different computer programs that rapidly leads to a final sizing of primary structure. It provides control over the planning, scheduling and coordination of the analytical efforts of several technical disciplines that have a direct effect on the sizing of primary structure. At

Grumman, these groups include aerodynamic configuration, weight analysis, contour development, structural design, structural analysis, mecahnical systems, structural temperature, loads and criteria, vibrations and flutter.

Each of the technical disciplines establishes mathematical models associated with its work, e.g., aerodynamic geometric grid systems, weights grids, structural idealizations, radiative, convective and conductive thermal models. The establishment and standardization of these models (in regard to sign convention and coordinate systems) makes it possible to transmit data between the various technical groups so that they can be used directly without additional hand or computer reprocessing. Additional programs are in development to obtain element thermal gradients and stresses in areas of discontinuity of temperature or structure.

Finally, the establishment of a data bank provides a central storage facility for all calculated intermediate and final calculated data. The data bank consists of stored magnetic tapes, catalogued listings, Calcomp plots, Orthormat drawings, DD80 microfilm, punched cards and engineering drawings of mathematical models.

The following list includes only those structural analysis programs that form part of the IDEAS system. It should be noted that any one of the programs could be used independently of the IDEAS cycle, if required.

- C1 - Mathematical Model Geometry Program
- D1 - Preliminary Structural Sizing Program
- D2 - Structural Properties Calculation
- S1 - Member Data Generator For Structural Models
- S2 - Loads Transformation Program (Surfaces)
- S3 - COMAP - ASTRAL Program
- S4 - Fully Stressed Design Program (Average Stress)
- S5 - Full Stressed Design Program (Nodal Forces)
- S6 - Member Force Conversion Program

- S8 - Loads Transformation Program (Fuselage)
- S9 - COMAP - Design Load Distribution Program
- S11 - Gust Load Transformation Program
- S12 - Internal Load Resultants Program (Surfaces)
- S13 - Non-Linear Corrections Program (Buckling)
- S14 - Structural Influence Coefficients For Aeroelastic Corrections Program
- S15 - Fuselage Inertia Load Beaming Program
- S16 - DD80 Member Loads Program (Graphical Display)
- S17 - DD80 Deflection Program (Graphical Display)
- S18 - Internal Member Loads - Report Format
- S19 - Internal Loads Resultants Program (Fuselage)
- S20 - Min. - Max. Search of Internal Load Resultants Program
- S21 - Net Section Loadings Calculated From Internal Loads
- S22 - Pressure Data Transformation Program
- S23 - Thermal Interface Transformation Program
- ASOP - Automated Structural Optimization Program

The following is a partial list of separate programs that have recently been used on various in-house programs:

- Axially Symmetric Shell Buckling (non-Linear Shallow Shell Iteration)
- General Unsymmetric Shell Analysis Program
- Structural Synthesis of Integrally Stiffened Panels Subject to Combined Shear and Compression Loading
- Z - Stiffened Panel Under Combined Shear and Biaxial Stress
- Inelastic Analysis of Isotroic and Anisotropic Structures
- Conventional Shear and Bending of Multi-bay Shell Structures

- General Beam Analysis of One Cell Frames, U-Frames and Curved Beams
- Advanced Composite Computer Programs

  SSBUCK - Compression Buckling of Simply Supported Panels

  FFBUCK - Compression Buckling of Fixed Edged Panels

  FSBUCK - Compression Buckling of Fixed-Simply Supported Panels

  BUCKLS - Shear Buckling of Plates Simply Supported

  NCRFFX - Compressive Buckling of Fixed-Free Plates

  STAB - Critical Laminate Compression Stresses for Filament Buckling, Laminate Instability, Etc.

  NOPHAT - Hat Stiffened Panel Optimization

  NOPTEE - Tee Stiffened Panel Optimization

  OPTPNL - Honeycomb Stiffened Panel Optimization

  OPLAM - Optimization of Multidirectional Laminates for Multiple Loading Conditions at Different Temperatures

  LAP - Strength Calculation of Single Overlap Bonded Joints

  STEPS - Strength of Symmetric Stepped Bonded Joints

  THRM1 - Thermal Stress Distribution in Composite Panels

  TRNS1 - Rectangular Rosette Data Reduction for Advanced Composite Materials

- Crack Propagation Due to Spectrum Loading Including the Effect of Time at Load
- Crack Propagation Due to Spectrum Loading Including Effects of Crack Growth Delay
- Fatigue Life Prediction of Notched or Unnotched Parts Under Spectrum Loading by Either Strain Cycling or Stress Cycling

- Fatigue Life Prediction of Lugs Under In-Plane Spectrum Loading
- Calculation of Plastic Stress Concentration Factors Based on Cyclic Stress - Strain Curve
- Quasi-Random Spectrum Mix for Use in Fatigue Life Prediction Methods
- Abbreviated General Thermal Analysis Program
- Calculation of Steady State Temperatures of Thermal Networks
- Calculation of Radiation Interchange Factors
- Calculation of Transient Temperatures of Thermal Networks Including Variable Thermo-Physical Properties and Mass Transfer
- Calculation of Equilibrium Temperature Distributions
- Optimization of Multi-Layered Slab Thicknesses for Given Thermal Inputs
- Charring Ablation Program
- Graphite Ablation Program
- Reentry Ablation Temperature Response
- T1 - Grumman Thermal Analyzer
- T3 - CONFAC Mod III (Configuration Factors for Thermal Analysis)

2.9.3 COMMONALITY CANDIDATES

The design, analysis, and testing of space shuttle structure will profit enormously from successful efforts to blend common design philosophy, present analysis techniques, and past experience. Prime candidates for such commonality include:

- Common design criteria and design philosophy i.e., tankage safety factors, fracture mechanics approach, qualification test procedures, and acceptance procedures
- Common usage of related computer programs i.e., F.S.D, STARS, ASTRAL
- Common usage of detail structural analysis procedures and supporting data i.e., Structural manuals and engineering manuals

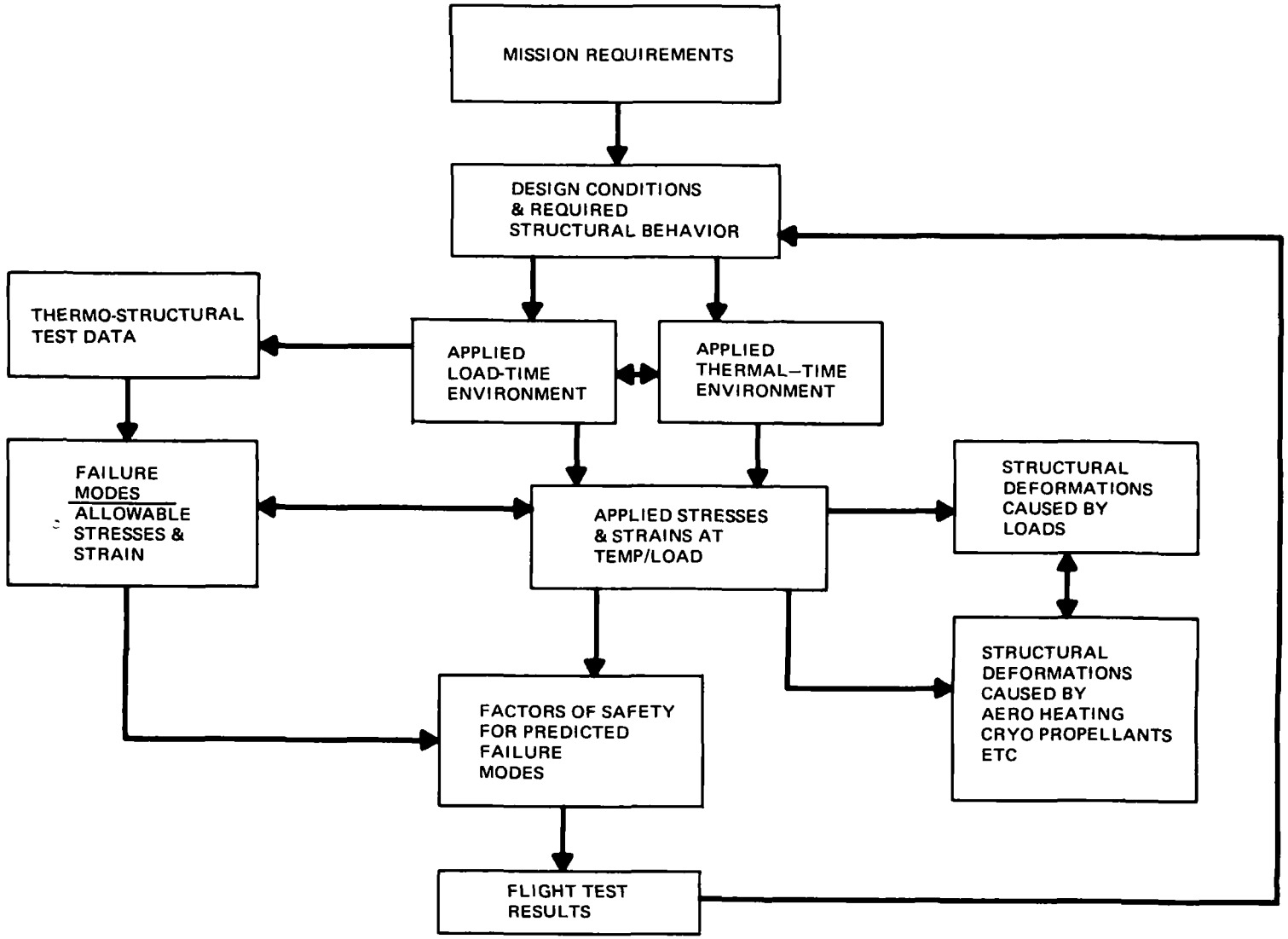

Fig. 2.9-1 Methodology Establishing Structural Integrity

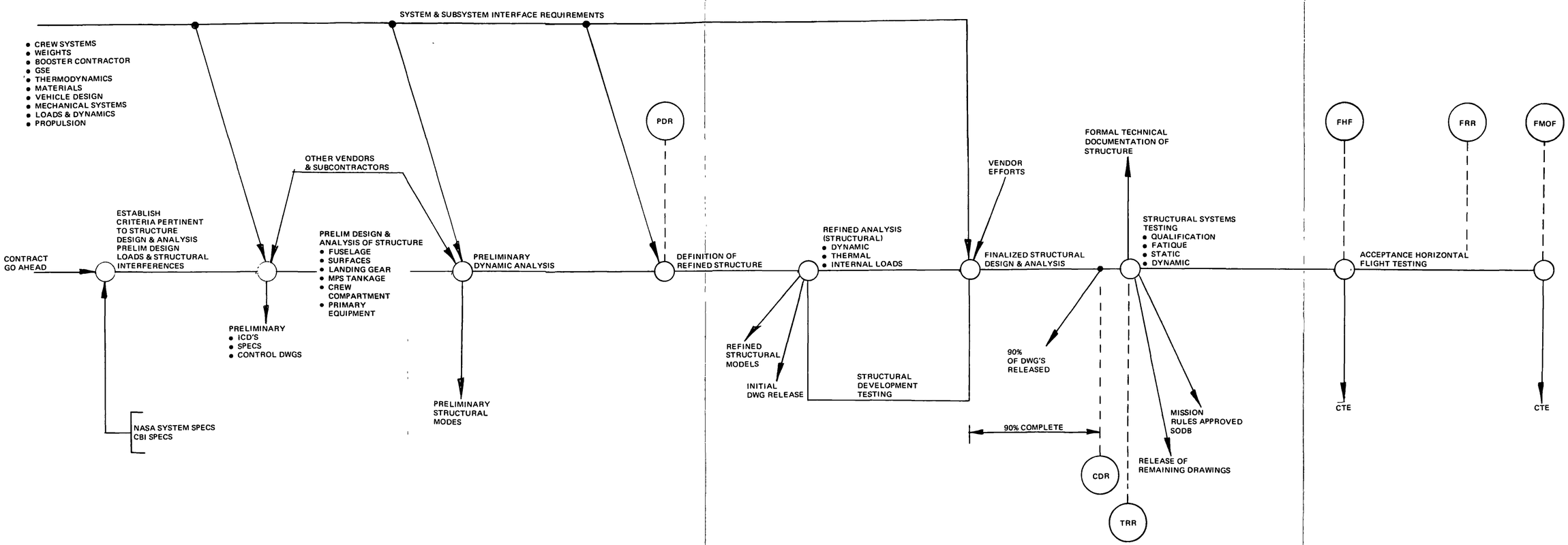

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Fig. 2.9-2 Structural Analysis Logic Network

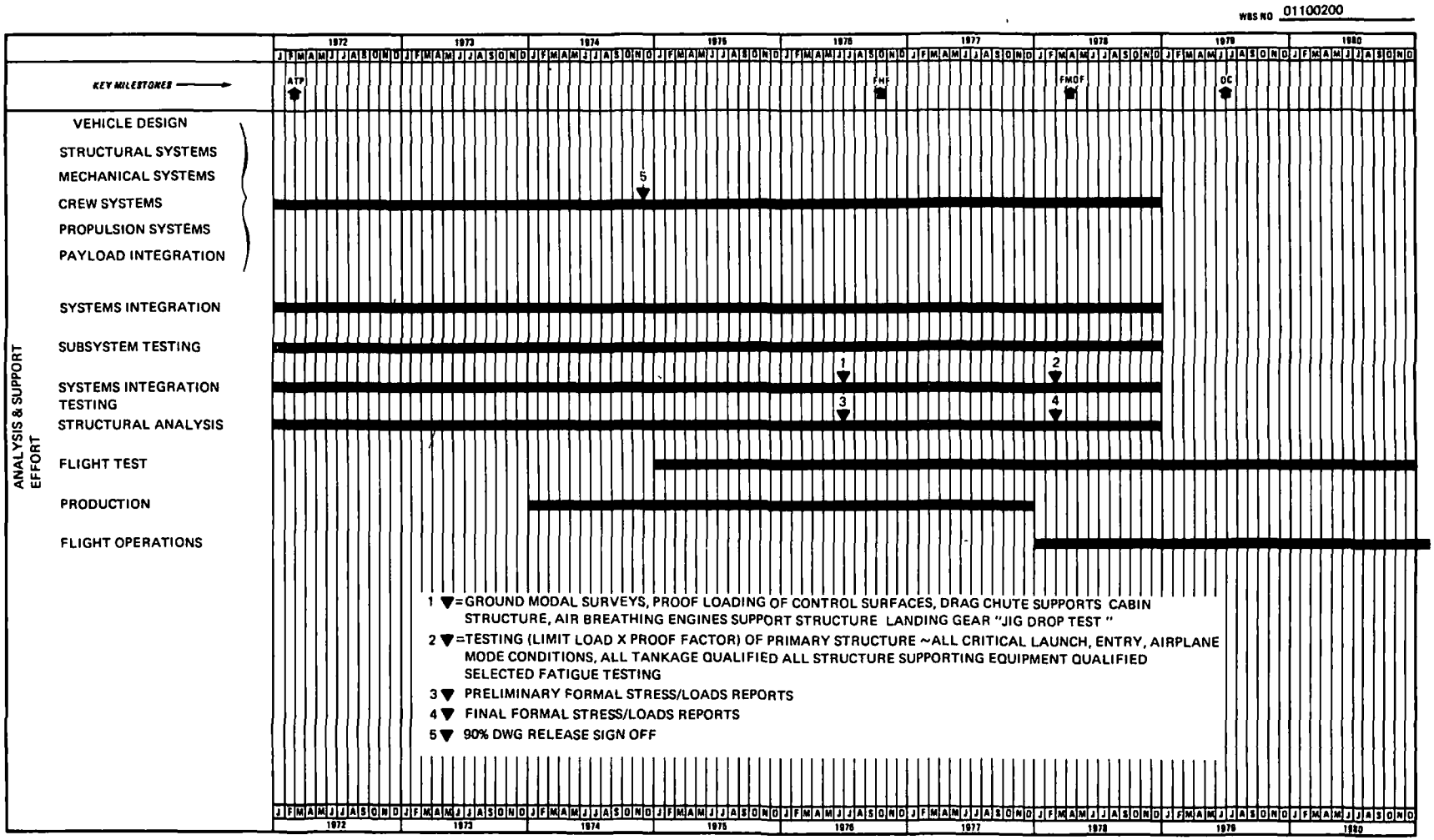

Fig. 2.9-3 Structural Analysis Schedule

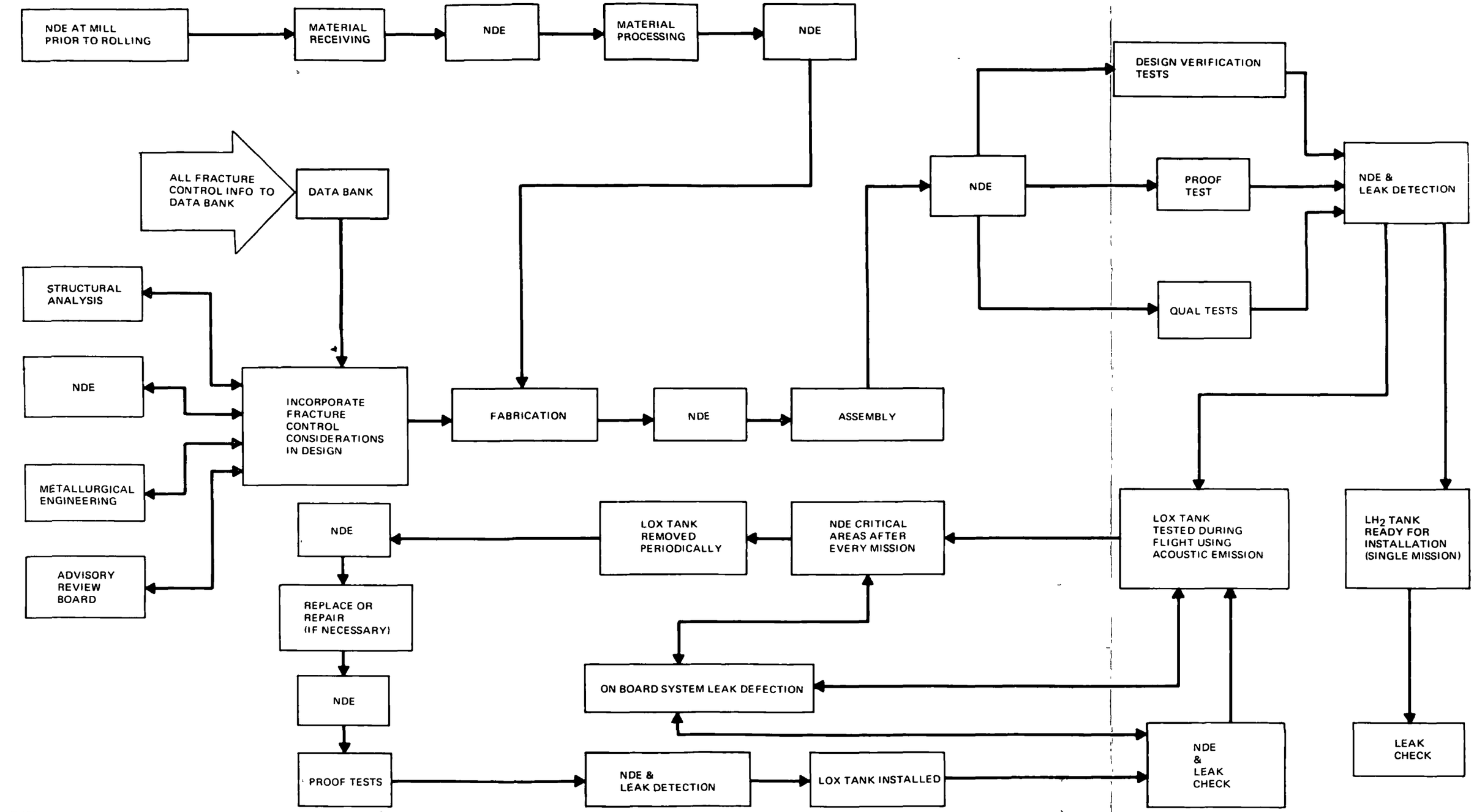

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Fig. 2.9-4 Fracture Control Plan

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2.10 THERMODYNAMICS

Thermodynamics is responsible for the definition and adequacy of the space shuttle thermal requirements and design. In accomplishing this, thermal analyses are performed on system, subsystem and component levels which are verified by performance tests. The thermodynamics organization is comprised of four groups: aerothermodynamics, vehicle thermal balance, thermo-propulsion and equipment thermal design. Thermodynamics also provides analytic support to EC/LSS, structural temperatures and the power generation groups.

2.10.1 AEROTHERMODYNAMICS

The aerothermodynamics group defines the aeroheating environment encountered during boost and reentry, and assists in formulating designs that optimize configuration and trajectory with regard to aeroheating parameters. Specific tasks are:

- Perform detailed aeroheating calculations for each point design
- Perform sensitivity analysis as affected by trajectory and configuration
- Initiate aerodynamic heating tests in ground facilities, defining models and instrumentation
- Review tests, analyze data, formulate design optimizations
- Develop theoretical and semi-empirical computer programs
- Assess expendable tank reentry design to define dispersion and pollution problem
- Provide liaison with NASA aeroheating panel

The key issue in this area is to provide accurate aeroheating environment predictions as early as possible to preclude costly TPS design iterations. This is accomplished by a comprehensive aeroheating analysis and test program. The choice and location of TPS material, design and insulation requirements are directly affected by the aeroheating inputs which depend upon flight trajectory parameters. Since the entire vehicle surface is subject to reentry heating, an accurate assessment of these inputs is required to

minimize TPS weight. The complex configuration of the orbiter, requires empirical definition of heat rates from subscale wind tunnel and shock tunnel tests to determine leeside, windward, interference and base heating characteristics.

Heat transfer testing is a tool for both defining the thermal environment and to support analytical methods. Initially, configurations are tested in wind tunnels using such survey-type techniques as phase-change-paint, schlieren photography and oil flows. Limited thin-skin-model thermocouple testing is performed to supplement the paint data and in areas not amenable to paint testing. This testing initially defines the thermal environment, indicates the impact of configuration changes, and uncovers problem areas early in the program.

In addition to wind tunnel testing, high energy facilities such as shock tunnels are used to evaluate the real gas effects on the various heat transfer phenomena. As the configuration matures, specific tests in wind tunnels and shock tunnels define such local problem areas as control surfaces, wing fillets, shock impingement and surface irregularities.

Testing on the final configuration is performed in wind tunnels and shock tunnels to validate the thermal environment under the expected range of flight conditions.

The orbiter test program uses 5420 hours of tunnel time, allocated as shown below:

Type of Model	Wind Tunnel, hr	Shock Tunnel, hr
Phase change paint	1920	
Thermocouple	800	1500
Pressure	500	500
Flow visualization	200	
Totals	3420	2000

The initial series of tests constrain the completion of preliminary designs, the second series constrains initiation of manned orbital flight testing through the flight regimes covered by test.

2.10.2 THERMO-PROPULSION

The thermo-propulsion group defines the thermal environment and assists in the design of thermal protection for all rocket engines, air breathing engines, cryogenic tankage, cryogenic fluid lines, heat exchangers and hydraulic system. The group defines engine plume characteristics and determines their effects on the orbiter and/or booster. Specific tasks are:

- Establish thermal math models of engines, tankage, lines and cryogenic fluids
- Define insulation requirements for on-orbit tanks, injection tanks, plumbing, tank supports, engine mounts and engine nacelles
- Define hydraulic cooling and/or heating requirements
- Assess ACPS plume heating on orbiter with subscale shock tunnel tests
- Assess ACPS engine soakback and aeroheating in recessed ports
- Assess ACPS propellent thermal conditioning
- Determine effects of main engine plume impingement/interaction on orbiter and booster

A significant cost and schedule savings is inherent in the LH_2 expendable tank design since it eliminates the development risks of fabricating reusable internal tank insulation. The external surface of the expendable tanks are simply spray coated with urethane foam insulation for ground hold and to minimize ice buildup. The foam is oversprayed with a non-porous ablator in local areas. Icing tests are planned early in the program to define the insulation thickness along with ground hold requirements. Additional tests will define the material properties required of the non-porous protective outer coating.

The ACPS nozzle penetrations are a localized heating problem which undergo early evaluation to select an optimum design. Wind tunnel tests are planned to evaluate the cavity and lip heating rates during reentry. A detailed analytic study evaluates: a) the baseline movable door design, b) bleed gas cooling and c) fabrication of a high temperature protection ring around the cavity lip or nozzle. The selected design will be defined during the detail design phase.

An early assessment of the baseline on-orbit tank purge bag insulation design is made relative to new Grumman advances in light weight dewar tank designs. The analytic study trades off system launch weight including purge components versus boiloff, complexity, reliability, safety, and maintenance. The insulation design with standoffs and seams is thermally tested and cycled to assure its adequacy for the shuttle mission. A full scale tank is fabricated for qualification testing under mission simulation with LH_2 to verify the design.

Another significant task is to define the main engine plume impingement/interaction on the orbiter and booster. The effects of plume heating while mated and during separation are assessed in the Grumman shock tunnel. The facility, test techniques and interpretation of data to full scale predictions have been well substantiated during LM plume impingement and fire-in-the-hole testing. Both thin film thermocouple and pressure measurements are used to define the heating rates. Early definition of the heat rates on the base shield due to possible recirculation at the center of the engine cluster is made during these tests.

2.10.3 VEHICLE THERMAL BALANCE

The vehicle thermal balance group establishes requirements for vehicle thermal control, due to the thermal interraction of structure, equipment and propulsion system. This group also determines the external and internal temperature-time history of the vehicle throughout its mission and defines the thermal requirements for the vehicle system, subsystems and components. Specific tasks are:

- Establish detail thermal math model of orbiter
- Establish ground and space environment incident on the shuttle vehicle
- Define temperature time history of critical components for design reference missions
- Provide interface between project and thermal laboratory for the evaluation of thermophysical properties
- Define and implement insulation and coating requirements for cabin, internal and external structure and system components
- Define ground purge requirements

- Maintain overall thermal management of orbiter and develop real-time temperature history for flight tests

A key function of this group is to integrate various subsystems into an optimized thermal configuration. A particular example is the impact of space thermal conditioning on the TPS insulation design.

A significant weight savings of TPS insulation may be achieved by selecting a low α_s/ϵ coating for the vehicle that eliminates attitude constraints to maintain low structural temperatures in orbit prior to reentry.

Analytical tradeoffs are made early in the program to assess vehicle weight for various low α_s/ϵ coating properties and trajectories as they affect insulation thicknesses and structural temperatures. Selected high temperature coatings such as Sperex VHT white paint, white pyromark and white porcelain enamel are tested for thermophysical properties simulating space and reentry conditions, to assure high emittance properties for reentry and structural rigidity during repeated cycling.

2.10.4 EQUIPMENT THERMAL DESIGN

The equipment thermal design group establishes requirements for thermal management of shuttle avionics and electrical power systems. This includes analysis and definition of cooling requirements and internal electronic packaging designs. The group provides detailed supervision of vendor thermal activities during design test, fabrication and qualification of flight hardware. Specific tasks are:

- Provide detailed thermal math models of fuel cells, APU, batteries, communication and navigation equipment
- Assess the thermal design of the fuel cell and APU fuel conditioning system
- Define power/thermal limits on wiring and circuit breakers
- Maintain power/thermal heat dissipation control for all equipments and mission time lines
- Analyze antennas subject to aeroheating and define thermal requirements
- Define thermal control system for liquid cooled and air cooled equipment

- Define heater/thermostat controls for equipment
- Generate thermal control requirements and thermal interface definitions for equipment specifications and ICD's

2.10.5 ENVIRONMENTAL CONTROL

Thermodynamics provides analytical support to EC/LSS to:

- Analyze integration and commonality
- Perform optimization of EC/LSS equipment
- Define consumable requirements during design reference missions
- Review vendor design, analysis and test
- Initiate and support system and component testing
- Analyze space radiator performance

2.10.6 STRUCTURAL TEMPERATURE GROUP

Thermodynamics supports the structural temperature group, to define critical structural temperatures using existing network programs and methods. The temperatures obtained are incorporated into thermal stress programs (as part of IDEAS - Integrated Design and Analysis System) to assess primary, secondary and TPS structure as affected by temperature.

2.10.7 ANALYTICAL TECHNIQUES

The thermodynamics section is an analytic group and relies heavily on math models to select and optimize thermal design requirements. The shuttle is analyzed for both point-design and off-design conditions to assure successful completion of its mission. Thermodynamics has developed numerous computer programs over the past 10 years that are directly applicable for analysis of the shuttle vehicle, subsystems, systems and environmental heat inputs as required by mission considerations. In addition analyses are developed for real-time flight operations.

Math Models

Math models are developed for the following:

- Large node math model of the orbiter vehicle, including structure, engines, tanks, cabin, payload, electronic equipment
- Main engines, OMS engine
- Attitude control engines
- Base heat shield
- Injection propellant tanks
- On-orbit tanks and main O_2 tank
- Fuel lines and cryogenic transfer
- Fuel conditioning and heat exchangers
- Crew cabin
- Payload compartment and docking tunnel
- ECS system
- Power supply system; including batteries, fuel cells, APU, wiring
- Hydraulic power lines
- Predict reentry heating
- Wheel well and tires
- Launch conditions, including purge
- External and internal design of electronic equipment and displays
- Plume characteristics; ACPS and main engines
- Plume impingement; ACPS
- Plume impingement and interference during separation
- Windshield

The following shuttle computer programs are currently available and are easily modified for special problems as they arise.

Aerothermodynamics:

- Strip theory
- Streamline divergence
- Free stream properties
- Swept cylinder (laminar)
- Swept cylinder (turbulent)
- Fay and Riddel stagnation point heating
- Rho-Mu (Boeing program)

Vehicle Thermal Balance

- Grumman thermal analyzer - transient & steady state with Calcomp plotting
- Small nodal network thermal analyzer for 360-67
- Orbital heat flux
- Goddard shadow factor
- Wing anti-icing
- Confac vertex condenser
- Orbital heat flux with Calcomp plotter
- Confac
- Solar diffuse
- Specular solar
- Script F
- Vertex validity
- Sphere vertex generator
- Graphite ablation

- Timeline sequencing program - mission simulation for use with Grumman thermal analyzer
- Multilayer superinsulation temperature profile

Thermo-Propulsion:

Same programs as used for VTB; plus:

- Propellant vaporization freezing
- Nozzle and plume analysis by method of characteristics
- Plume impingement program
- Ablation program
- Multi-compartment venting program
- LH_2 and H_2 thermophysical properties - NBS
- LO_2 and O_2 thermophysical properties - NBS

Equipment Thermodynamics:

All of the above; plus:

- Wire bundle analysis

ECS

All of the above; plus:

- ECS-1 subsystem level
- ECS-2
- ECS-3 subsystem and system level
- Plate fine heat exchanger with space radiator
- Heat pipe optimization
- Plate fin heat exchanger with condensation

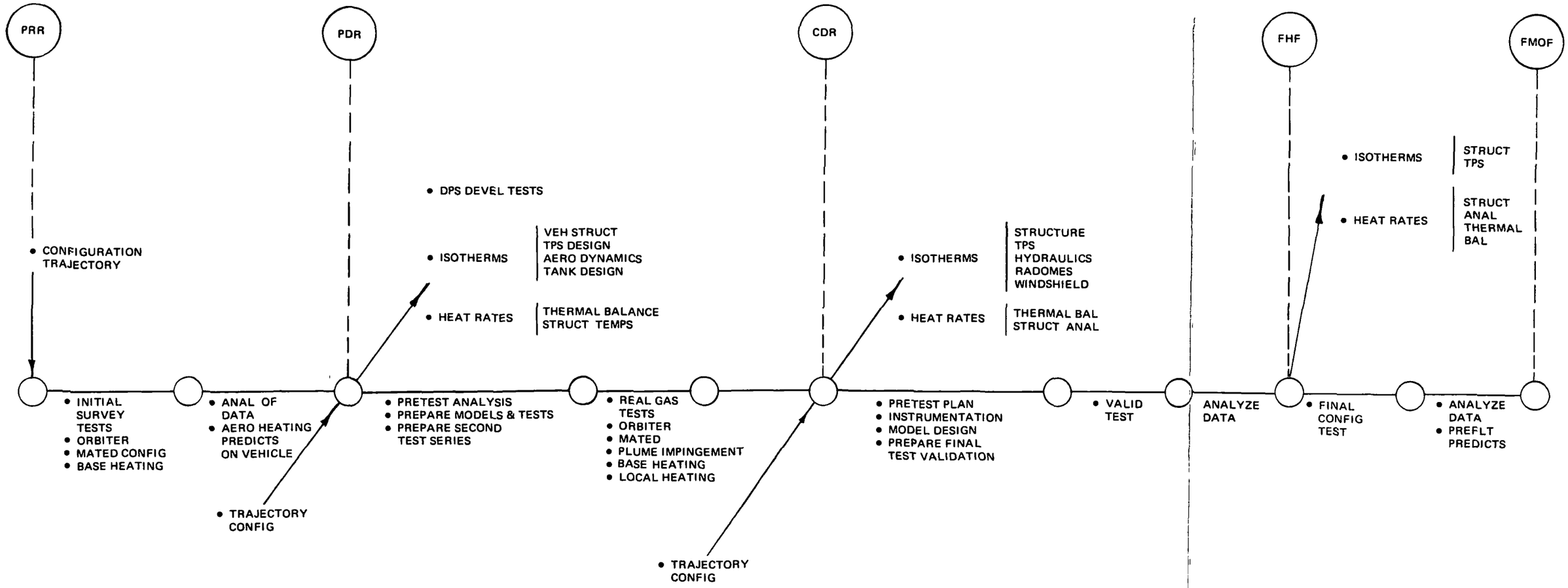

Fig. 2.10-1 Thermodynamics Logic Network (Aerothermodynamics)

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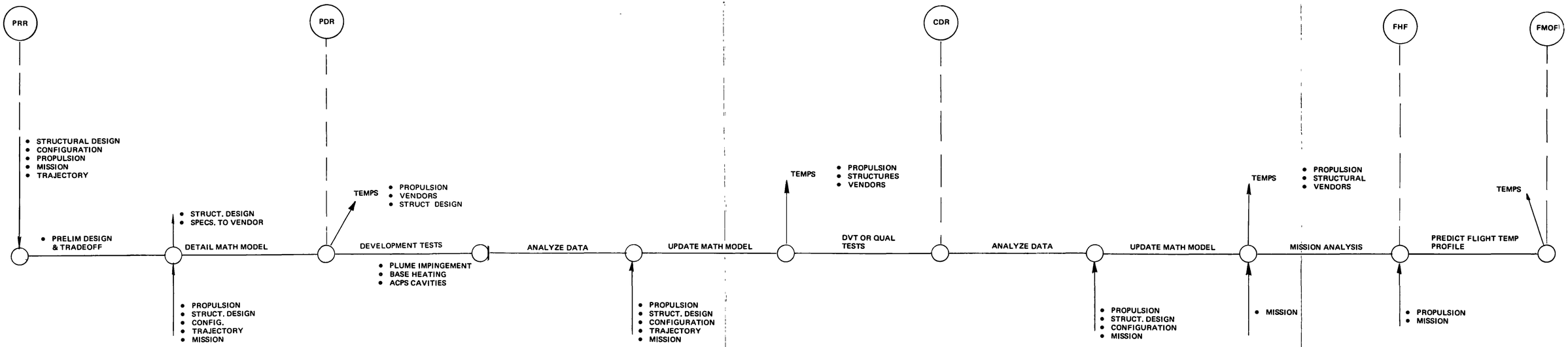

Fig. 2.10-2 Thermodynamics Logic Network (Thermopropulsion)

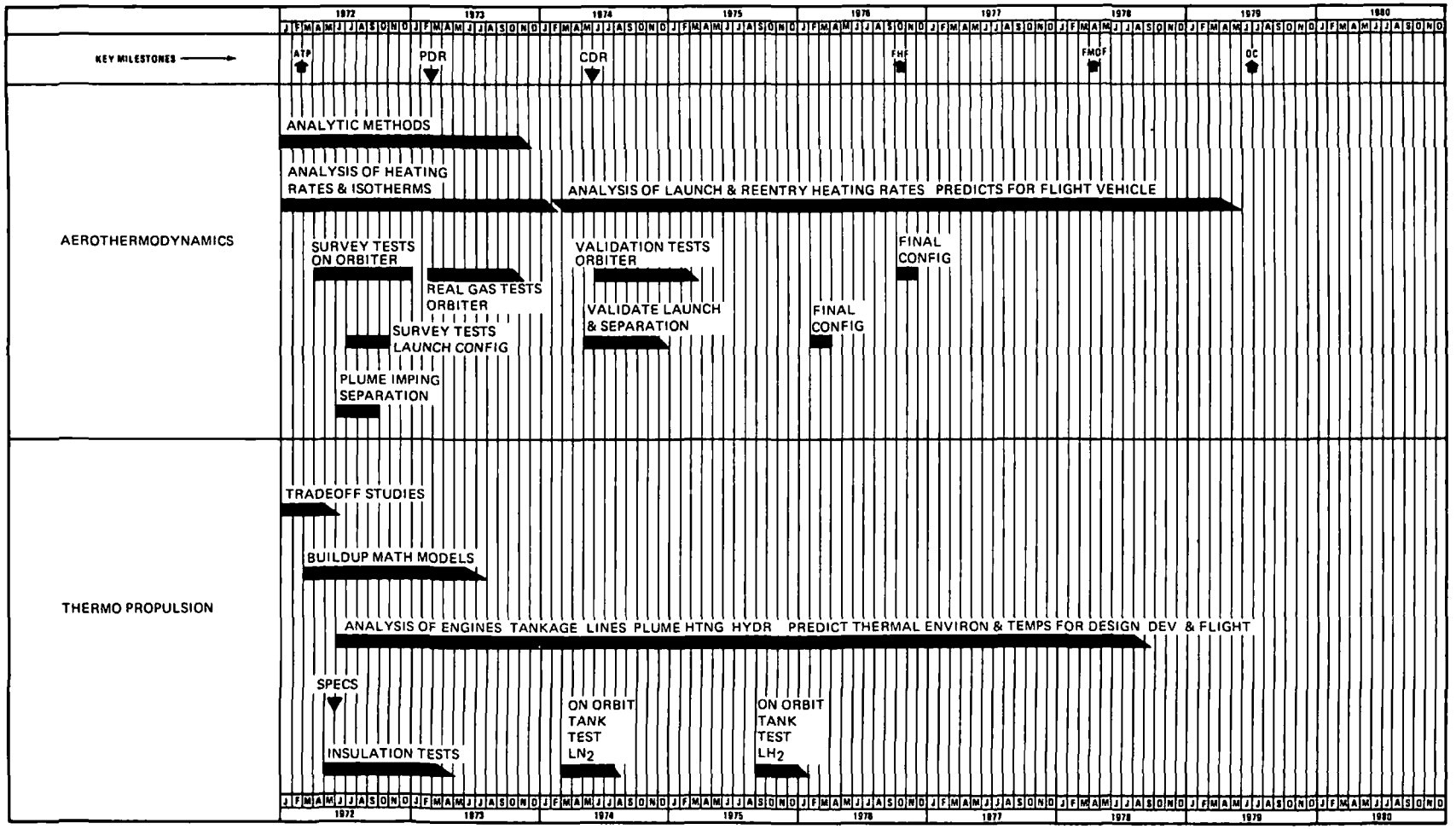

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Fig. 2.10-3 Vehicle Design Analysis Thermodynamics Schedule (Sheet 1 of 2)

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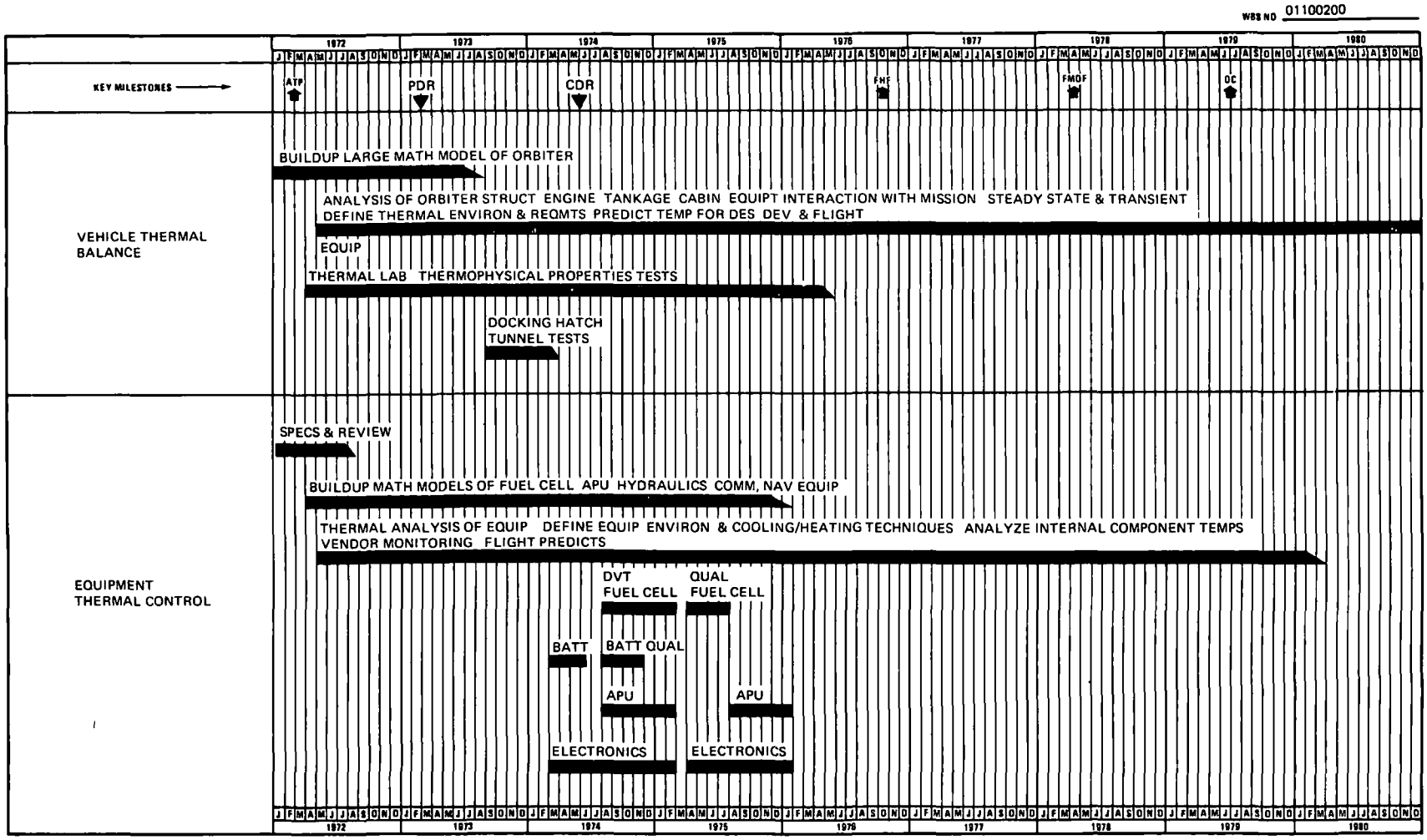

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Fig. 2.10-3 Vehicle Design Analysis Thermodynamics Schedule (Sheet 2 of 2)

TABLE 2.10-1 SYSTEM CERTIFICATION REQUIREMENTS (Sheet 1 of 2)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Demo
On-Orbit LH_2 Tank Thermal Design						●				●	
On-Orbit LO_2 Tank Thermal Design						●				●	
Main H_2 Tanks Thermal Design	●								●		
Orbiter Cabin Thermal Design	●									●	
Orbiter Vehicle Thermal Balance	●										●
ECS Radiator Thermal Design						●			●		
OMS Rocket Engine Thermal Design					●				●		
Main Rocket Engine Thermal Design					●				●		
ACPS Rocket Engine Thermal Design					●				●		
Base Heating		●						●			
Power Supply Fuel Cell Thermal Design					●				●		
Power Supply APU					●				●		
Communications						●		●			
Navigation, Guid. & Control						●		●			

TABLE 2.10-1 SYSTEM CERTIFICATION REQUIREMENTS (Sheet 2 of 2)

Certification Requirement	Certification Method						Level of Assembly				
	Analysis	Simulation	Similarity	Common Usage	Test		Component	Assembly	Subsystem	Comb. Subsystem	Flight Demo
					DVT	Qual					
Displays & Controls						●			●		
Reentry	●					●					●
Crew Compartment	●									●	
Payload Compt. Thermal Design	●									●	
Docking Tunnel & Hatch					●				●		
ACPS & APU Thermal Conditioning					●				●		

TABLE 2.10-2 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

Item	Common	Potential Common	Not Common	Remarks
Launch Configuration Wind Tunnel Testing		•		Potential of using similar, if not identical models from the individual orbiter and booster tests and use them in a launch configuration test.
Thermal Design of Main Engines		•		Same engines on both vehicles - possible commonality of base heating and extended engine design are similar.
Thermal Design of Attitude Control		•		Same engines for maneuvering - could be common if positioned and cooled similarly on each vehicle.

TABLE 2.10-3 FACILITY REQUIREMENTS LIST (Sheet 1 of 2)

Title & Description	New	Exist.	Contr.	Govt.
Thermal Laboratory		●	●	
● Cryogenic insulation development		●	●	
● Thermophysical properties measurements		●	●	
● High temperature coating development & measurement	●			
● High temperature superinsulation development		●	●	
● Ablative insulation development	●			
● Thermal foam evaluation		●	●	
● Window optical properties		●	●	
Environmental Test Laboratory		●		
● Radiator T/V tests		●	●	
● Ice buildup studies on expendable tanks		●	●	
● Attitude control engine thermal vacuum tests		●	●	
● Small scale OMS tank thermal vacuum test, including purge		●	●	
Cold Flow				
● Cryogenic flow in pipes, valves, etc.		●	●	
● Gas generator heat exchanger tests		●	●	
● ACPS & APU fuel conditioning		●	●	

TABLE 2.10-3 FACILITY REQUIREMENTS LIST (Sheet 2 of 2)

Title & Description	New	Exist.	Contr.	Govt.
White Sands Test Facilities				
• AC rocket engine thermal tests		●		●
• Main rocket engine thermal tests				●
Fuel Cell Test Facility	●			
• Fuel cell thermal tests	●			
• Fuel cell fluid heat exchanger tests	●		●	
LH_2 Test Labs	●			
• LH_2 test; OMS tanks				
- Qual - thermal, cycling, vibration		●	●	
- Accept - thermal, vibration				

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TABLE 2.10-4 FACILITY REQUIREMENTS LIST,
WIND TUNNEL TESTING

Title & Description	New	Exist.	Contr.	Govt.
Grumman Facilities				
• 36-in. Hypersonic Tunnel		•		
• Shock Tube Plume Facility		•		
NASA Facilities				
Langley				•
• 24-in. Hypersonic Variable Density Tunnel		•		
• 36-in. Continuous Hypersonic Tunnel		•		
• 4-ft Unitary Supersonic Tunnel (High Speed Leg)		•		
Air Force Facilities				
AEDC				•
• Hypervelocity Tunnel		•		
Private Facilities			•	
• 96-in. Cornell Aeronautical Lab. Shock Tunnel		•		

TABLE 2.10-5 COMPUTER SUPPORT REQUIREMENTS

	Year					
	'72	'73	'74	'75	'76	'77
Machine Time, hr/yr						
360-75	622	1200	1200	1230	1230	1230
360-67	125	240	240	250	250	250
360-30	125	240	240	250	250	250

2.11 LOADS AND DYNAMICS

2.11.1 TASK DESCRIPTION

The responsibility of Loads and Dynamics is to ensure that the orbiter design loads, both static and dynamic, are defined sufficiently to result in a structurally adequate vehicle. Additional tasks are the supporting development effort and verification of a flutter free orbiter which has low internal acoustic levels and is constructed of sonic fatigue resistant structure.

The groups comprising Loads and Dynamics are:

- Loads and Criteria
- Experimental Dynamics
- Acoustics and Vibration Environments
- Vibration and Flutter Analysis

2.11.1.1 Task Summary

- Identify initial critical mission segments for loads prediction, flutter prevention, and sonic fatigue exposure
- Determine design load envelopes and fatigue loads
- Determine stiffness, mass, or design constraints needed for adequate flutter and Pogo margins
- Determine constraints on structural design required for satisfactory sonic fatigue resistance
- Identify shock and vibration requirements for qualification testing of subassemblies and components
- Provide loads for structural testing
- Perform scale model tank slosh tests

- Perform propulsion system component and assembly tests for Pogo
- Review and approve flight restrictions as well as instrumentation and flight test plans pertinent to the loads and dynamics effort
- Reduce and appraise both ground and flight test data in the technical areas of loads, flutter, vibration, and acoustics

2.11.1.2 Task Approach

2.11.1.2.1 Loads Prediction

Loads for the orbiter vehicle will be required for all phases of the mission from ground winds on the launch pad through landing and taxi loads on the orbiter at the end of the mission. Going through a typical mission, the first set of loads needed are those associated with transport to and erection of the orbiter at the launch site. Here, the valuable experience and background data gained on the LM program will enable Grumman to predict these loads with a high degree of confidence. Once the booster and orbiter are erected the next critical loading problem is that of ground winds. Analysis of this condition is not considered meaningful; this is the job for a good dynamic model. Here Grumman has unique experience in very high angle of attack testing of winged vehicles. The model must be designed in a special manner to handle the high loads and yet be light enough to possess dynamic similarity. Grumman has done this job and the experience to do it again is still retained.

During launch, two classes of loads are significant; the dynamic loads associated with lift-off transients and engine thrust modulation. These loads are the critical conditions which design certain portions of the vehicle. For these loads, analysis should be adequate (with specific propulsion system tests) and has been the approach taken by Grumman on similar problems in the past. The successful LM program can attest to this.

The primary dynamic problem in this phase of the mission is Pogo. This airframe-propulsion system interaction requires careful attention to prevent occurrence of high g level oscillations. A detailed analytic mathematical model of the coupled booster-orbiter as well as the orbiter alone is used to obtain the highly coupled free-free modes of the respective configurations. Significant propulsion items such as feed lines and engines are included in the math model. Pogo stability calculations are initially performed using

transfer functions empirically derived for the engines to be used. Modifications to the system at this stage are undertaken to improve the stability of the vehicle. As the design is firmed up detailed propulsion tests are performed of the specific engines, the feed lines and pumps, the propellant tanks and any other significant propulsion items. This data is Continually being updated in a Pogo analysis to assure that the space shuttle is free from detrimental vibrations.

Other significant loads during launch are aerodynamic and are primarily due to wind shear/gust. This condition must be covered by a combined analysis and model test program. Models of the booster and orbiter with pressure instrumentation will be tested to determine the airload distributions of the orbiter and booster in proximity to one another. These airload distributions are used with existing maneuver and gust digital computer programs to obtain the complete flight load conditions during launch. This combined experimental/analytic technique has been used recently on the F-14 aircraft. (It should be mentioned here that the F-14 fuselage airloads were very significant because of the wide fuselage; the shuttle orbiter is also expected to have significant fuselage airloads because of its large size relative to the wing).

The critical loads in the next phase of the mission are expected to be caused by docking maneuvers. Here again, the docking analyses performed on the LM program form a base of computer programs and experienced personnel.

Reentry loads are not expected to be critical in their own right; however, the structural temperatures existing during reentry make any loads significant. The airloads for this Mach regime must rely heavily on wind tunnel model test programs.

Once back in the atmosphere, Grumman computer programs can be used to predict cruise, maneuver, gust, landing, and taxi loads.

Initial loads prediction will be based upon analysis only, supplemented by any appropriate general aerodynamic tests and isolated special loads tests. Lifting surface and wing-body computing programs are used extensively to derive aerodynamic data for all configurations. Existing calculation procedures are then used to estimate loads at lift-off, at maximum $q\alpha$ and $q\beta$, ascent wind shear, reentry, gust during flyback, maneuver, and landing. Inspection of the resulting loads then permits generation of a loads envelope of all conditions suitable for initial sizing of structural members. While the structural

sizing effort is being conducted, the predicted loads are being recycled and refined. The major test data for the refinement stage will be obtained from a heavily instrumented wind tunnel model which will measure local pressures on the surface of the orbiter at the required Mach number and attitude.

2.11.1.2.2 Flutter Prediction

Orbiter flutter is a possibility during flight because of the high dynamic pressures encountered during launch, abort, and cruise back sections of the flight profile. In addition, although the reentry condition occurs at low dynamic pressures, the degradation in structural stiffness due to temperature may result in critical flutter conditions on reentry.

Initial flutter predictions will employ analytic techniques only; modes and frequencies of the elastic structure are calculated using flexibilities obtained from finite element analyses. Flutter predictions are then performed using Kernel, Stark, or Mach Box programs. Follow-on model testing is used to refine the results of the analysis. Initial component model testing verifies the analysis of the surfaces only whereas complete scaled flexible models are used for the final flutter proof testing. A unique problem will exist in the model simulating reentry conditions for the structural stiffness being modeled must reflect the effects of the thermal environment.

The results of the flutter prediction effort is used as a guide in planning the modal vibration survey (see subsection 10.5) and in planning the flight flutter test program.

2.11.1.2.3 Acoustic and Sonic Fatigue Prediction

As in the case of loads and flutter, this area is treated initially by pure analytic tools and as the configuration is firmed up simple and then more complex testing is employed. The acoustic predictions are first performed using empirical techniques for both aerodynamic and rocket engine noise. This data determines the extent of the acoustic insulation needed for the crew comfort problem and also forms the basis for subsequent sonic fatigue calculations. Simple tests such as transmission loss of candidate acoustic treatment and simple panel sonic fatigue tests are performed to "flesh out" the analytic skeleton. In the final testing full scale air-conditioning mock-ups and full scale structural components will be tested to verify the adequacy of the acoustic treatment and demonstrate the sonic resistance of the structure.

The acoustical and fluctuating pressure levels are the basis for determining environmental vibration requirements for the critical phases of the mission. Since current procedures for determining vibration levels rely on extrapolating statistically analyzed vibration responses on past vehicles, there is some unavoidable conservatism inherent in them. Past experience on Apollo has shown that such conservatism in equipment requirements for electronic and electromechanical equipment can be expensive due to the development engineering effort required. Most electronic equipment is located in the cabin which is an integral non-redundantly mounted pressurized unit. The structural test model of this section outfitted with equipment mockups on flight weight support structure would be subjected to an acoustical and low frequency vibration test, in order to demonstrate structural integrity and to furnish more realistic equipment vibration levels. These tests will be conducted prior to the pressure test described in paragraph 10.2.6. The relatively small size and shape of the cabin combined with the statically determinate mounting system provides for ease of testing the cabin as a separate unit in existing facilities.

2.11.1.2.4 Dynamic Aspects of An External Non-Integral Tank Orbiter

Susceptibility of the external and non-integral main propellant tanks to dynamics problems has been noted and the analytical and testing program provides assurance against any significant difficulties. Wind tunnel tests on a 1/75 scale model have already shown preliminary indications that the external hydrogen tanks act to suppress buffet onset in the delta wing of the H3 orbiter. Buffet loads on the tanks as well as on the lifting surfaces are determined using a dynamic wind tunnel model, and Grumman's past experience on store carrying aircraft will be used to ameliorate any problems, should they develop. Single-degree-of-freedom flutter on the external tanks is also investigated using this model to provide assurance of an adequate margin against this phenomenon. Accurate description of the low frequency flexible vehicle modes is required for optimizing the vehicle automatic control system. The prediction of these frequencies and the verification by test is described in more detail in paragraph 2.11.1.2.1. Note that preliminary frequency calculations indicate that the non-integral LOX tank orbiter frequencies were no lower than those for an integral LOX tank configuration. Model vibration tests of the booster, orbiter, and mated configuration are discussed in paragraph 3.2.5.3.1 of Volume 1.

2.11.2 ANALYTICAL TECHNIQUES

The analytical computer programs currently available for performing in-depth studies by the loads and dynamics group include both programs within the Integrated Design and Analysis System (IDEAS) and separate programs that cover special topics such as sonic fatigue.

IDEAS is a management system for the integrated use of many different computer programs that rapidly leads to a final sizing of primary structure. This very powerful tool has been used with great success on the F-14A fighter designed by Grumman. In this application, flight and landing loads, both external and internal, were obtained quicker, cheaper, and with more accuracy than had been possible in the past. IDEAS provides control over the planning, scheduling and coordination of the analytical efforts of several technical disciplines that have a direct effect on the sizing of primary structure. At Grumman, these groups include aerodynamic configuration, weight analysis, contour development, structural design, structural analysis, mechanical systems, structural temperature, loads and criteria, vibrations and flutter.

Each of the technical disciplines establishes mathematical models associated with its work, e.g., aerodynamic geometric grid systems, weights grids, structural idealizations, radiative, convective and conductive thermal models. The establishment and standardization of these models (in regard to sign convention and coordinate systems) makes it possible to transmit data between the various technical groups so that they can be used directly without additional hand or computer reprocessing.

Finally, the establishment of a "data bank" provides a central storage facility for all calculated intermediate and final calculated data. The data bank consists of stored magnetic tapes, catalogued listings, Calcomp plots, Orthomat drawings, DD80 microfilm, punched cards and engineering drawings of mathematical models.

In support of past aircraft and spacecraft design and development programs, Grumman has originated a large number of computing programs which are of a general nature and

have direct application to the design and development of a successful orbiter. A partial listing of these programs and some of the features of each are:

- Subsonic Lifting Surface and Supersonic Lifting Surface - These two programs are in constant use at Grumman and are used to predict local pressures on surfaces of general planform due to arbitrary angles-of-attack
- Body Air Loads - Recently used with considerable success on the wide bodied F-14A, this program is directly applicable to the orbiter. Using values of angle-of-attack, sideslip angle, Mach number, and dynamic pressure, the program calculates vertical and lateral running loads at specified fuselage stations
- Aeroelastic Effects - Using structural influence coefficients and lifting surface data, this program adjusts the aerodynamic loadings for the effects of flexibility
- Airplane Maneuvers - This program computes five-degree-of-freedom time histories for symmetric, roll, and yaw maneuvers. Control system characteristics including stabilization system characteristics can be included. Output of the program are airplane motions, rates, and accelerations as well as control surface positions as a function of time. This program is a general purpose analysis which uses either theoretical or experimental aerodynamic coefficients as input and as such is applicable to EOS configurations with no program modification
- Unsymmetrical Landing - This program permits calculation of six-degree-of-freedom motion of a flexible aircraft and accounts for the articulated behavior and bending flexibility of several types of landing gears.
- Vibration Modes A - This program calculates free-free or restrained modes of vibration and natural frequencies of any system having known mass and flexibility influence coefficients
- Flutter A - This program is a simple flutter calculation using strip aerodynamics. Additonal flutter analyses use lifting surface techniques, i.e., Kernel, Stark, and Mach Box. All are operational on Grumman computers
- Longitudinal Discrete Gust - This program computes response of the vehicle and the attendant loads resulting from flight through a discrete gust having a one-minus-cosine profile

- Transient Response - This program calculates the transient load and motion time history of a complete system to an arbitary forcing function. Interaction between input and response is not included in this particular program

The computer programs listed above are a small sample of those currently used in the loads and dynamics effort at Grumman. All the above mentioned programs are general purpose programs needing little or no modification for application to the orbiter.

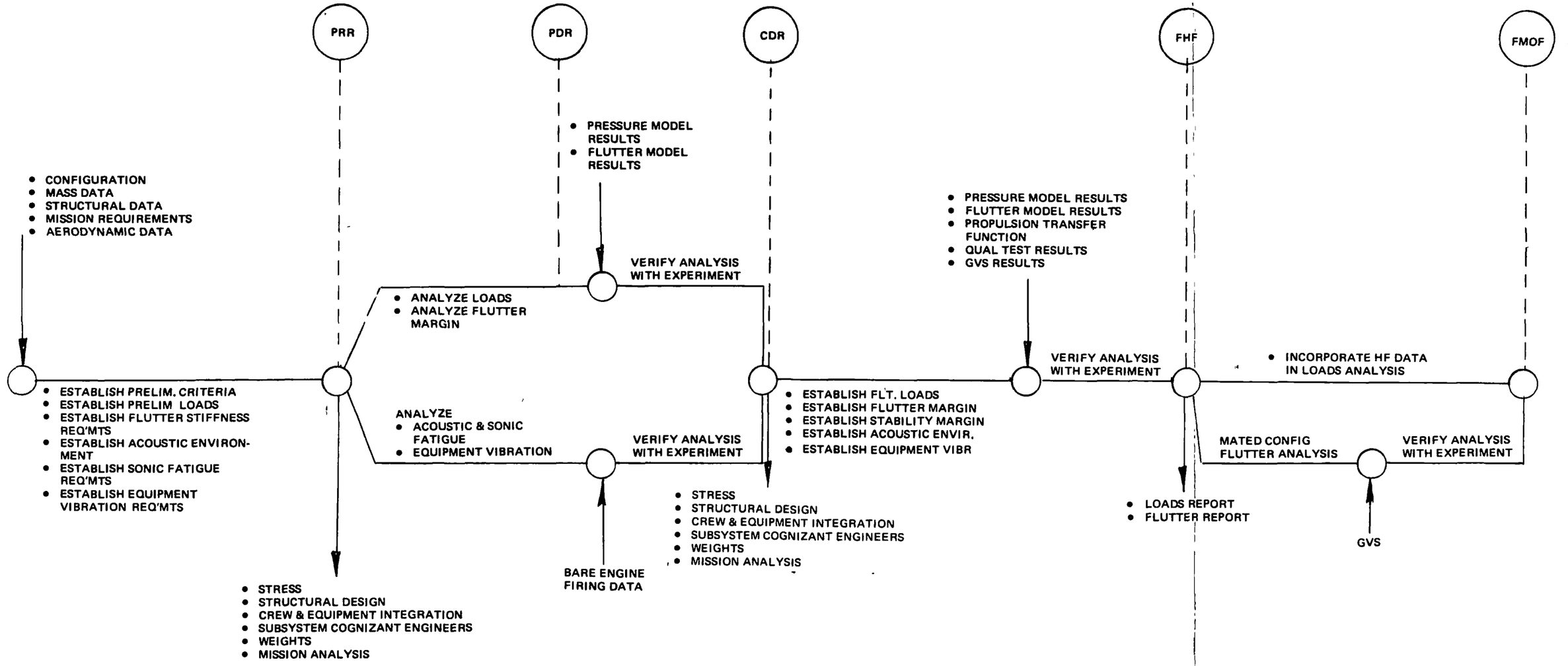

Fig. 2.11-1 Loads and Dynamic Logic Network

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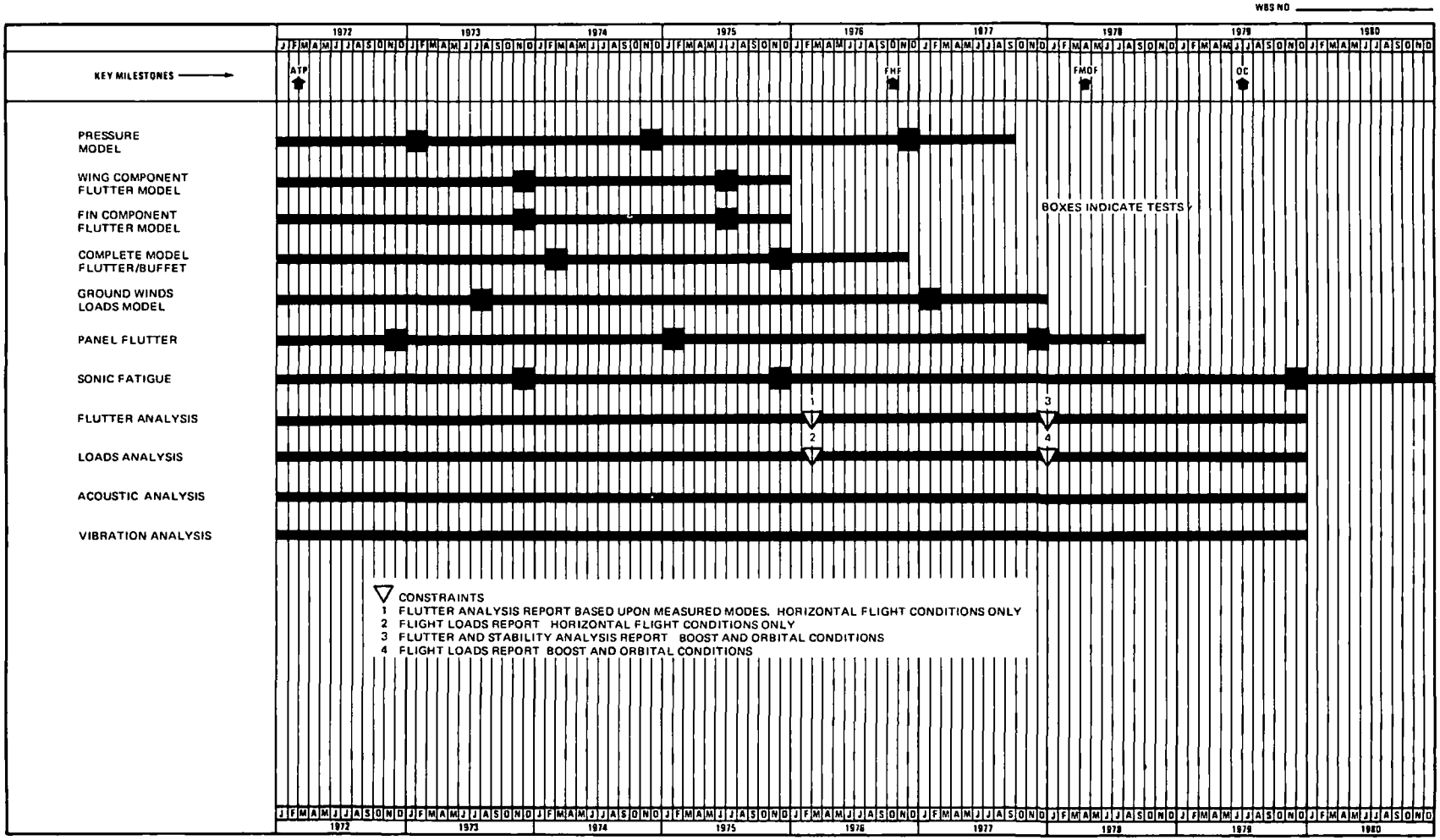

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Fig. 2.11-2 Loads and Dynamics Schedule

2.12 MASS PROPERTIES

2.12.1 TASK DESCRIPTION

The only practical approach to real weight control is through a vehicle wide effort throughout the entire design phase directed by an aggressive and thoroughly competent technical staff. Support of this effort in terms of timely and accurate weight analysis and weight status accounting is an essential adjunct to the direct attack on overweight design. This staff will be supported by the entire engineering organization and backed by our own specialists in weight analysis, weight optimization and subcontractor weight control. This is consistent with the highly successful weight control efforts we have conducted on past programs, most recently the F-14 air superiority fighter. The F-14 actual weight at first flight was within 1 1/2% of the specification empty weight. This was achieved without a contingency allowance in the weight estimates.

Figure 2.12-1 and Table 2.12-1 illustrate that Grumman has achieved a high weight control performance level through:

- Experienced personnel (one engineering department for aircraft, space, etc.; many advanced designs: Lunar Module, Orbiting Astronomical Observatory, A-6 All-Weather Attack Aircraft, E-2 Early Warning Aircraft, F-14 Air Superiority Fighter, Tracked Air Cushion Research Vehicle)
- Realistic designs (i.e., minimum practical weight within the constraints of cost and state-of-the-art)
- Timely and accurate design loads (IDEAS)
- Accurate estimates (e.g., structural sizing with design/manufacturing non-optimum factors derived from experience on past designs; accountability checks for splices, access doors, etc.)

TABLE 2.12-1 GRUMMAN WEIGHT PERFORMANCE

YEAR			SPECIFICATION				
1 CONTRACT AWARD	2 FIRST FLIGHT	3 MODEL	4 WEIGHT EMPTY	5 CONTINGENCY WEIGHT	6 WT EMPTY W/O CONTINGENCY	7 ACTUAL WEIGHT AT FIRST FLIGHT	8 % WEIGHT GROWTH (7-6)/6
5/58	4/61	A-6A	22,680	650	22,030	23,724	+7 69
7/58	10/60	E-2A	34,213	875	33,338	34,365	+3 08
8/63	1/65	C-2A	31,216	550	30,666	30,745	+0 26
5/64	7/65	EA-6A	28,098	416	27,682	27,934	+0 91
12/64(1)	1/69	LM-5(2)	30,000(2)	0	30,000	33,297	+10 99
2/69	12/70	F-14A	35,979	0	35,979	36,492	+1 43

(1) THE ORIGINAL PHASE A CONTRACT WAS AWARDED 10/62 THE 12/64 DATE USED HERE REFLECTS THE INCORPORATION OF FINAL MISSION DESIGN REQUIREMENTS AND IS CONSISTENT WITH THE AIRCRAFT PHASE C CONTRACT AWARDS

(2) LM-5 WAS FIRST LUNAR LANDER THE CONTROL WEIGHT ESTABLISHED 12/64, WAS 32,500 LB THE ESTIMATED WEIGHT IN 12/64 WAS 30,000 LB

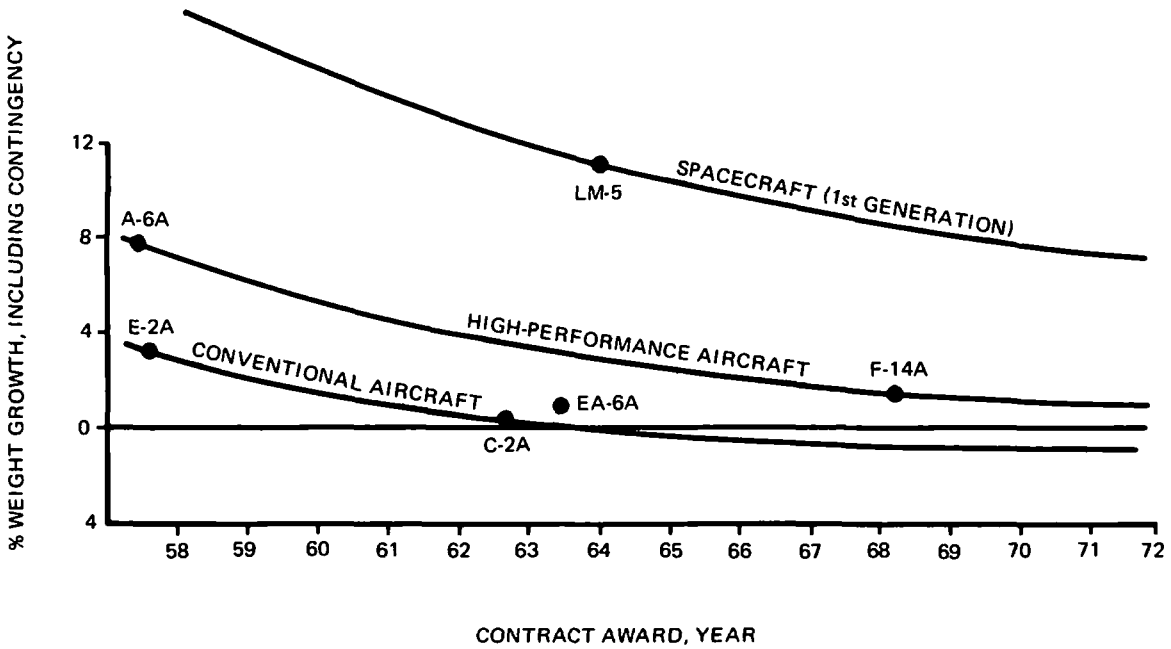

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Fig. 2.12-1 Grumman Weight Performance

- Rapid and accurate electronic data processing (EDP) weight accounting system for computing mass properties and reporting current versus target weights by design responsibility and/or functional coding
- Weight optimization engineers (structural and mechanical) responsible for the weight estimates and the "delivery" of these weights by exercising engineering drawing authority (i.e., signature required)
- Subcontractor weight control engineers responsible for weight estimates, subcontract weight negotiations and active weight control

2.12.2 TECHNIQUES

The following is a synopsis of some of the specifics of the detail functioning of the mass properties group and how it controls vehicle weight.

2.12.2.1 Weight Analysis

Monitoring the status of the design relative to target weights will provide NASA and Grumman management with early trends on the overall vehicle as well as the individual design responsibility disciplines.

Detail target weights will be developed and available to management and the individual design groups prior to the start of design (the DDT&E phase). These targets will be based on a comprehensive analysis of the orbiter requirements and will be broken down into the lowest functional details possible in the permissible time frame; i.e., minor subassemblies, specific frames, longerons, skins, etc. The total of all the target weights will equal the control weight less the contingency growth allowance and suitable reserves.

Detail part limit weights will appear on engineering drawings for parts requiring a controlled process (machining, chem-milling, etc.) prior to the time manufactured parts are presented for inspection. Parts will be weighed as a routine part of the inspection process and rejected for material review disposition if their weight exceeds the permissible limit.

2.12.2.2 Reporting

Electronic data processing techniques have been developed allowing compilation of weight status by design responsibility, module and total vehicle on a timely basis and in

printed format suitable for management review on whatever time interval is warranted; bi-weekly summaries are planned based on past experience, as being most fruitful, however, this period can be lengthened or shorted at will to suit the development program.

Interim reporting can be provided to reflect week-to-week changes in vehicle weight. The interim report uses the latest computer program summary as a base and incorporates CCB decisions, updates to current stowage lists, and updates of vendor and contractor weights. On the Apollo program, the interim weekly/semi-monthly weight status reports were used by members of the CCB in reaching decisions on additions to the spacecraft.

These computer programs also provide NASA with direct printout in suitable format to satisfy the design data reporting requirements. This comprehensive weight status permits reasonable and timely policy decisions affecting the intensity of the weight reduction effort such as to avoid "over kill" at unnecessarily high cost and schedule delay. Further, they permit concentration of optimization effort on the areas of maximum gain.

The EDP program and techniques essential to effective weight control, as described above, also provide the necessary support of other engineering disciplines in the form of mass data output for determination of loads and criteria, aerodynamics stability, control and flying qualities investigations, flutter and vibration, etc. It also outputs material mix data by module and entire vehicle with capability of discrimination by machined parts, forging, etc.

This weight analysis accuracy is shown on Table 2.12-2 in a comparison of calculated weight empty and actual weight empty at first flight.

2.12.2.3 Subcontractor Weight Control

Sellers and associate contractors providing components and complete systems for the orbiter must also be actively controlled and monitored if an effective program of weight management is to be exercised. During recent programs dating back into the late fifties, Grumman has developed very effective and efficient procedures for controlling the weight of subcontracted airframe and equipment design. The magnitude of subcontracted systems and equipment in recent programs in terms of percentage of weight empty guarantees (not including GFE) is as follows. LM - 41%, EA6B - 18%, Gulfstream II - 36%, F-14 - 40%.

E/2.12

TABLE 2.12-2 COMPARISON OF CALCULATED WEIGHT EMPTY AND ACTUAL, AT FIRST FLIGHT

Year	Model	Calculated Weight, lb	Actual Weight, lb	Diff	% Error
1960	A-6A	23,766	23,724	-42	-0.18
1960	E-2A	34,459	34,365	-94	-0.27
1964	EA-6A (Proto)	27,386	27,400	+14	+0.05
1964	C-2A	30,865	30,745	-120	-0.39
1965	0A0 (A-1 Proto)*	3,494	3,500	+6	+0.17*
1967	LM Ascent + Descent Stage	9,400	9,411	+11	+0.12
1970	F-14A No. 1	36,469	36,492	+23	+0.06

*Moment of inertia critical; difference was 2.65%, allowance by NASA ±5.0%

Subcontractor weight control performance on our recent F-14A fighter is shown on Table 2.12-3. Note that the subcontractors were originally signed up for 515 lb less than our comparable guarantee to the Navy. The subcontractor specifications did increase due to prime contractor changes but the final weights are only 22 lb greater than the comparable guarantee to Navy. This history reflects tough negotiation and rigid control.

The salient features of a successful subcontract program as employed in the past are:

- Grumman weight control specifications for sellers
- Subcontract weight guarantees tightly defined
- Sellers data requirements to define and clarify weight control analysis and accounting procedures suitable to their operation and compatible with ours
- Evaluation of all seller change proposals (SCP's). To establish weight impact and effect on guarantees

TABLE 2.12-3 F-14A SUBCONTRACTED WEIGHTS (LOT I)

	Grumman Guarantee To Navy	Original Seller Spec Wt, lb	Current Seller Spec Wt, lb	Current Wt, lb	Current Wt vs Grumman Guarantee
Avionics	857.6	839.0	868.2	872.6	+15.0
Mechanical Design	3,892.0	3,608.9	3,843.0	3,853.5	-38.5
Propulsion/ Environmental Control	916.0	874.6	879.5	901.7	-14.3
Associate Contracts	4,473.0	4,240.0	4,379.3	4,513.7	+40.7
Structural Design	26.0	37.0	37.0	48.0	+22.0
Weight Empty Total	(10,164.6)	(9,599.5)	(10,007.0)	(10,189.5)	(+24.9)
Useful Load	1,498.3	1,448.3	1,448.3	1,496.1	-2.2
Total Subcontracted Equipment	(11,662.9)	(11,047.8)	(11,455.3)	(11,685.6)	(+22.7)

- Continuous technical liaison between cognizant Grumman subcontractor weight control engineers and the sellers to ensure that an efficient design approach is being followed and that reporting is being done clearly, accurately and timely
- Strong consideration of monetary penalties for overweight design

Where necessary, Grumman personnel are assigned and remain in residence at the seller's facility. Other disciplines assigned to the seller facilities do tend to relate to their own specialty and if encumbered with additional duties, naturally must set orders of priority and spread themselves thin. On large subcontracted developmental systems it can be advantageous to have Grumman weight control represented at the seller facility.

2.12.2.4 Design Loads - Timely

Accurate and timely structural load determination saves airframe weight. If structural arrangements are optimized for the wrong loads it is frequently impractical to achieve optimum weight for the right loads by the time they become available. To provide final loads at the earliest possible time Grumman uses the Integrated Design and Analysis System (IDEAS).

It is a series of specific computer programs (including the weight's W_1 program) for applied loads derivation which effectively reduces this operation to less than 25% of previous methods. Design criteria in the form of component net shears, bending moments, torsions and member loads are furnished for all desired and stipulated criteria. This is a fully operational system which was developed and used with great success in the design of the F-14 vehicle; it is a system unique in the aerospace industry.

2.12.2.5 Weight Optimization - In House Design

Grumman's weight optimization specialists working in close unison with the design engineers and other analytical specialists (producibility, reliability, maintainability, etc.) combine their efforts to produce optimum designs which meet or better the target weights established earlier. The weight optimization engineers signature is mandatory on each detail drawing before it can be released for detailing and to manufacturing engineering for tooling design. This provides adequate working level authority to ensure due consideration of weight as a normal part of design. It also precludes crash weight saving programs aimed at "locking the barn door after the horse has been stolen" with the attendant upward revisions to cost, schedule delays and patchwork effect. Consistent design, optimized to the desired extent are produced on time and at least cost.

Cost criteria for weight reduction are established early in the pre-design phase whereby the inherent worth of weight reduction is defined and can be used as tradeoff cost per pound criteria for design decisions.

Examples of F-14A weight optimization are:

- Original concept on aft fuselage was to have shear carrying engine doors only. Using the full depth of the nacelle as bending structure (increased beam depth) saved 104 lb
- Nacelle inner and outer skins originally aluminum with titanium splice bands at wing main frames. Changing to one piece titanium saved 127 lb
- Wing outer panels 6-6-2 titanium upper cover in place of 6-4 titanium saved 62 lb
- Wing center box welded upper cover in place of all bolted interference fit fasteners saved 79 lb

- Titanium fasteners in place of steel, in wing outer panel ribs, saved 12 lb
- Nose radar bulkhead: Beryllium strips in place of aluminum for stiffness requirement saved 7 lb

2.12.3 H-33 MINIMUM WEIGHT/PERFORMANCE RISK

Because of sensitivity of payload to vehicle weight, a realistic and practical orbiter design approach was used to ensure design goals. Examples are:

- The wing structural weight is relatively insensitive to load changes because the low aspect ratio, high thickness ratio wing results in 50% of the exposed area in minimum gage material. Therefore, weight is a much less than linear function of load
- The major portion of the body structure is designed by the 3g end boost load. The load factor is a maximum design value and not subject to variations in analysis. The load will vary only with orbiter lift-off weight
- The floating (i.e., non-integral) main propellant tanks, and cabin are divorced from fuselage primary structure and, therefore, the level of confidence is significantly increased in the analysis
- Realistic top heating estimates result in all the primary structure being covered with a thermal protection system (TPS). Therefore, any increase in temperatures will result in a gradual increase in TPS panel weight, not a stepped increase due to the addition of panels
- The TPS consists primarily of high confidence level metallic panels; only 11% of the TPS area consists of external insulation. In addition, 33% of the area consists of Haynes 188 and the unit weights are based on actual test panel weights
- The payload bay and the removable airbreathing engines were located close to the basic vehicle cg to minimize cg travel. Also, the delta wing is relatively insensitive to errors in basic vehicle cg estimates

However, if weight growth does occur, the external tank orbiter has capability to maintain the required delta V by either of the following:

- The external H_2 tank can be increased and the internal O_2 tank can be increased within existing configuration lines. This orbiter can accept an increase in propellant without orbiter configuration change
- The H_2 external tank can be increased in size and the O_2 tank can be maintained by changing the O/F ratio within acceptable rocket engine limits. Again, no orbiter configuration change

2.12.4 LOGIC AND CONSTRAINT

Mass properties analysis and control is a process of continual refinement of data. As the design solidifies, improved loads are available and rational analysis techniques of ever increasing complexity are employed to later become the basis for the CEI specification control weights. As discussed in an earlier paragraph, detail loads are available very early in the design phase thanks to the IDEAS program. Thus, our detailed target weights are based on near final loads, not guesswork.

As the detailed drawings start to emerge from the design groups our weight analysis personnel calculate (first from early conceptual layouts, then from complete layouts and finally from released drawings) the weights and enter the pertinent raw data into the EDP system. This provides a continually updated and current mass properties forecase of ever increasing accuracy which is available and distributed to all interested parties; cognizant design group engineers, program management and the customer. Our mass properties EDP program includes the functional coding required to meet the MIL-M-38310A specification design data requirements, an event sequence (which provides automated mass data output for various phases of the mission), 3 axis cg locations, shape and dimensional data to allow computer calculation of detail part and total vehicle moments and products of inertia, material and AMPR codes, etc. Thus, outputs of this program fulfill the requirements of such disciplines as aerodynamics, loads, flutter and vibration, structural analysis and others on a timely basis. This program is a marriage of those used successfully on the Lunar Module and F-14 weight control tasks.

Using this mass properties EDP program on the LM enabled us to meet all our contractual reporting requirements and due dates as well as providing us with valuable in house data. This data was used for monitoring and trending the weight of the LM and for the support of other engineering disciplines.

TABLE 2.12-4 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

Item	Potential Common	Common	Remarks
Mass Properties EDP Program IBM 360/75	•	•	Booster and orbiter contractors could most likely use the identical program for mass properties accounting. This would facilitate the preparation of total systems mass data from GLOW right through the entire mission.
Weight Distribution Program (W_1, IDEAS) IBM 360/75		•	

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TABLE 2.12-5 FACILITY REQUIREMENTS LIST

Title and Description	New	Exist.	Contr.	Govt.
Four Mobile Electronic Weighing Equipment - For weight and cg determination (X axis) of the orbiter vehicle, to be used at Grumman, KSC and the eastern and western test ranges.	•		•	

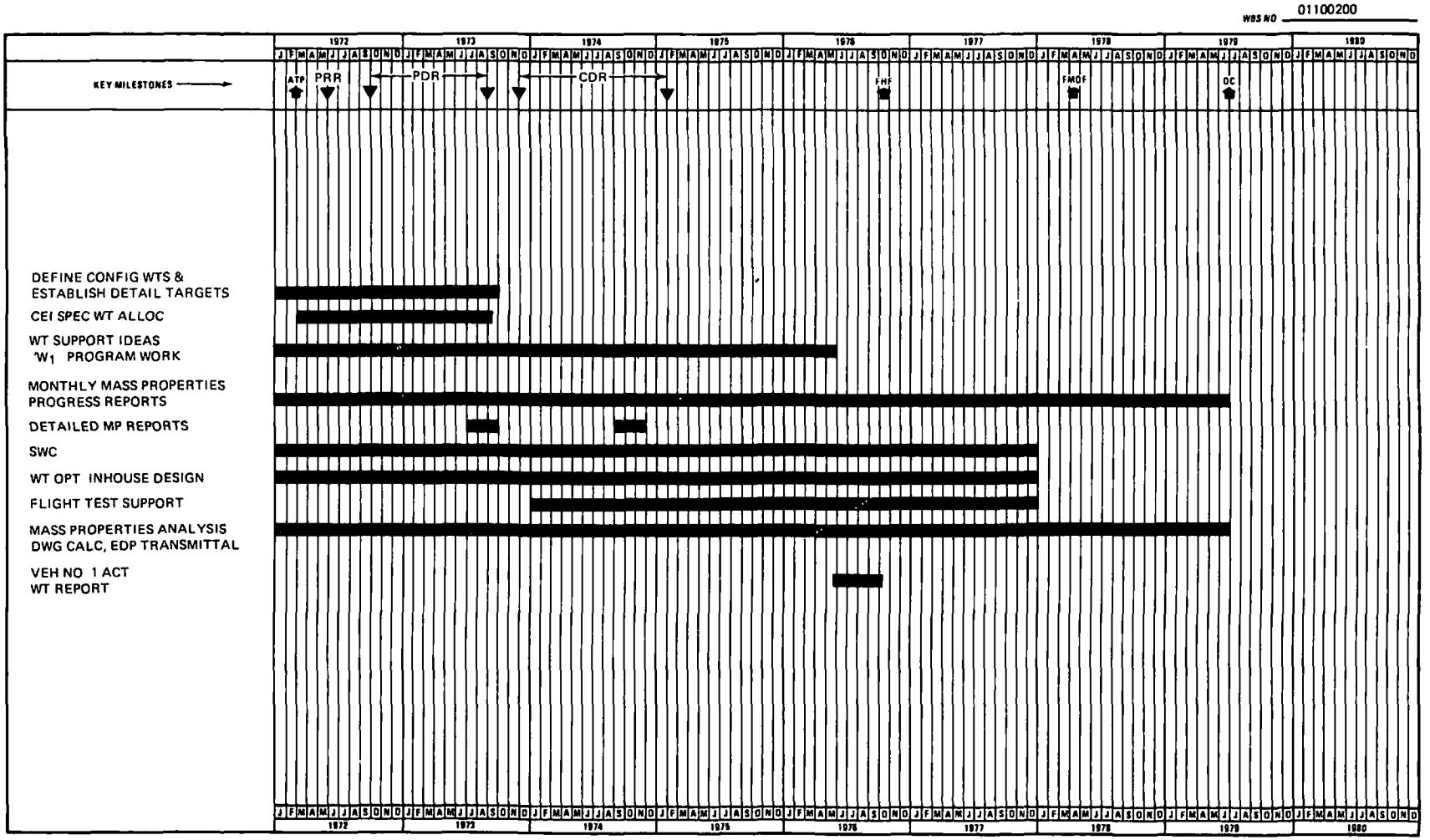

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Fig. 2.12-2 Mass Properties Schedule

2.13 TRAJECTORIES

2.13.1 TASK DESCRIPTION

This subsection presents the systems engineering plan to define the flight trajectory and performance required to accomplish the orbiter missions, and to develop and verify an integrated Guidance, Navigation and Flight Control System (GN&FCS). The plan ensures a closely coupled integration synthesis of the functions of system and analysis, system integration and development, software development, mission trajectory design, and software/hardware system performance verification, to achieve flight readiness status. The engineering task logic and constraint flow plan is shown in Fig. 2.13-1 and the schedule is shown in Figure 2-13-2.

2.13.1.1 System Synthesis

This phase (see Fig. 2-13-1) is initiated using baseline vehicle and mission requirements contained in the CEI specification and other appropriate documents defined at contract go-ahead. The tasks develop engineering information required for the PRR and PDR milestones.

Trajectory analysis will be conducted for all mission phases and abort conditions. The principal output from this task will be: delta V and propellant requirements for the MRPS, OMS, ACPS propulsion subsystems for purpose of vehicle/tank size design freeze; entry cross-range and footprint capability as a function of TPS design factors; mission trajectory profiles, G&N trajectory requirements; vehicle flight envelope (dynamic pressure, mach number, acceleration, etc.). This task is an iterative process involving improved definition of vehicle weight, aero and propulsion characteristics.

System requirement and trade studies are performed for the GN&FCS in order to define functional and performance requirements for the total system, and for the subsystems such as sensors (IMU, optical, etc.), actuators, ACPS, flight computers and electronics, and interfaces. This task will integrate automatic and manned flight control modes, support manned flight simulation studies and incorporate simulator results. Simulation and

system development test requirements will be defined for the GN&FCS. The basic laws, or equation systems, for navigation, guidance, and control will be synthesized and used for system stability and performance analyses and for computer sizing.

The principal outputs will be: GN&FCS functional configuration and performance requirements; integrated flight control system report; performance and interface specifications; interface control documents; GN&FCS flight computation requirements (memory size, computation and sample rates, etc.); flight simulation and system development tests; GN&C flight software verification and configuration control procedure.

2.13.1.2 System Development

This phase (see Fig. 2.13-1) consists of comprehensive system design and analysis, producing data to support GN&FCS and vehicle design freeze at the CDR, and completion of avionics specifications.

Detailed analysis and development of the software for navigation, guidance, stabilization and control for all mission phases will be done. This is the software formulation phase resulting in the software requirements document, from which coding of the flight computer program will be done. Additional data from the manned flight simulation program will continue to be incorporated as system refinement progresses. Vehicle aeroelastic dynamics, aerodynamics aero heating, and propellant slosh dynamics models will be improved using refined data for use during system analysis/software development. Latest analysis and data on sensor, actuator, and computer/electronic predicted detailed characteristics will be used.

Trajectory analysis will develop comprehensive mission design trajectories for principal and alternate missions; develop refined subsystem critical design trajectories; refine abort trajectories and separation dynamics; provide refined G&N requirements and support G&N software development. Comprehensive reentry guided trajectories and dispersions will be refined for final TPS design criteria.

The following documents will be updated to support firm avionics specifications release and vehicle CDR: GN&FCS functional configuration and performance requirements integrated flight control system report; performance and interface specification; interface control documents; software requirements document; mission trajectory profile and consumables report

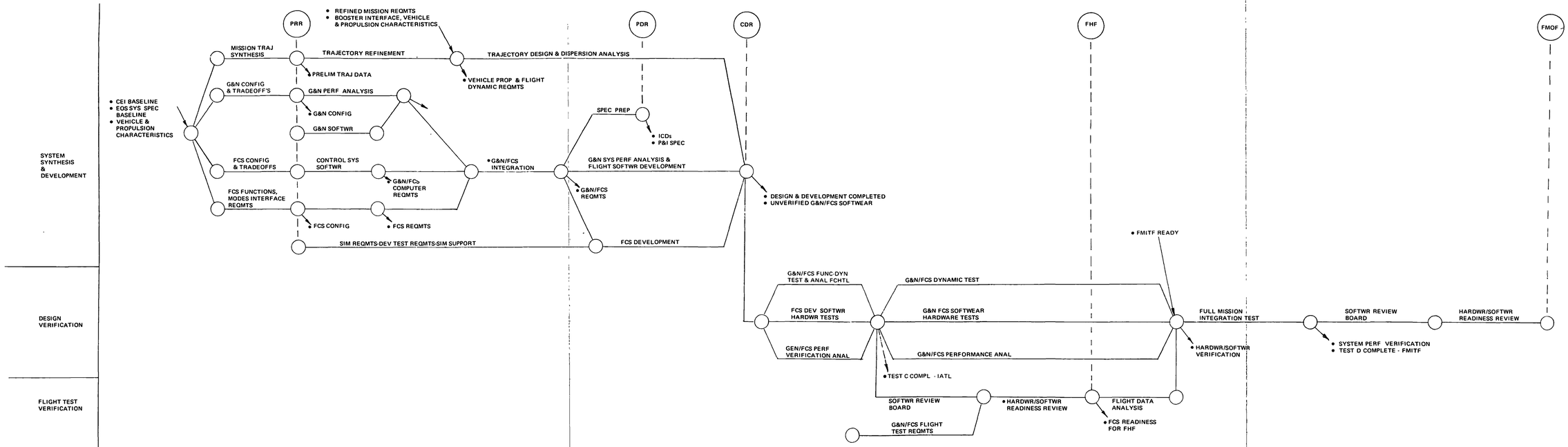

Fig. 2.13-1 Guidance, Navigation and Flight Control Logic

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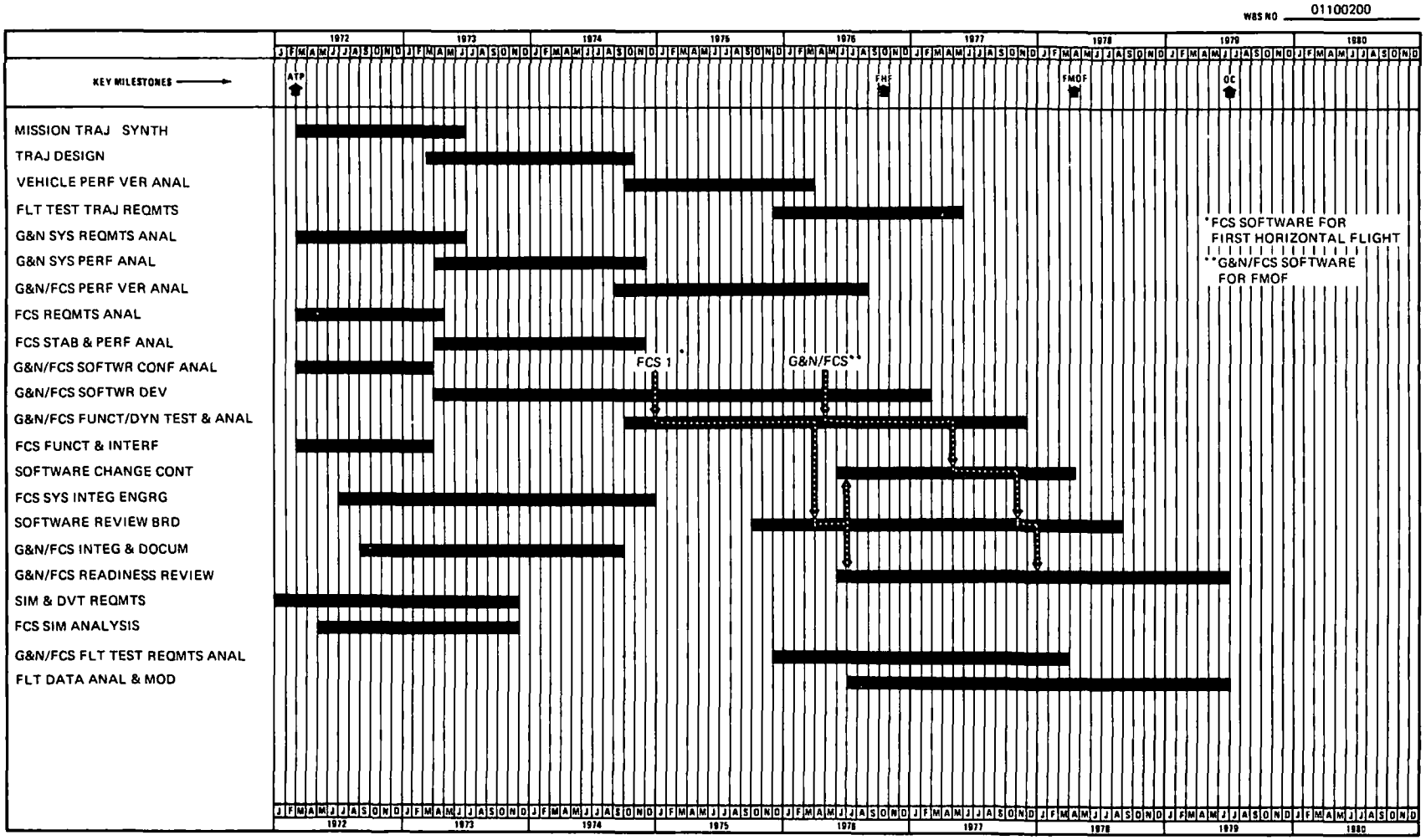

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Fig. 2.13-2 Trajectories, G&N/FCS Schedule

2.13.1.3 System Design Verification

This task consists of a closely integrated series of development test and system verification analysis. Component and system test data for the GN&FCS systems will be analyzed, and system flight performance will be predicted using the observed test data. Any hardware/software modifications, or equipment tolerance changes required will be made and re-tested.

The GN&FCS flight software will be development tested with the avionics sensor (IMU)/ computer equipment using a flight attitude table driven by flight dynamics simulation computer, for a closed loop dynamic-functional check of the vehicle stabilization and control functions. (Test B) Subsequent software development testing can be done in the avionics laboratory (IATL, subsection 10.6) without closed loop motion excitation of the sensors. Software verification testing will be accomplished on the FMIT (subsection 10-6).

The GN&FCS flight software will be configuration-controlled and verified for flight readiness by the software review board.

Mission trajectory design and vehicle performance analysis will be verified, periodically incorporating the latest propulsion performance test data, vehicle design characteristics, and G&N performance.

2.13.1.4 Flight Test Verification

The principal tasks during this phase consist of: engineering support for flight test planning; modification of analytic tools for use in postflight data analysis; engineering support for factory checkout and flight checkout for GN&FCS systems; flight test data analysis; engineering support for additional GN&FCS ground testing support of flight test.

2.13.2 GUIDANCE, NAVIGATION AND FLIGHT CONTROL SYSTEMS CERTIFICATION REQUIREMENTS

2.13.2.1 Functional Requirements - Certification Tests

- Test A - Dynamic performance tests of electrohydraulic actuators, on local structual stiffness with inertia loads (aero surface and rocket engines), and drive electronics. (FCHTL - subsection 10.6)

- Test B - Closed loop flight simulation with FCS sensors; simplified six-degree-of-freedom flight dynamics driving flight attitude table with sensors mounted; integrated avionics RACU, data bus, computer, essential to FCS function; simplified crew station controls and displays; development testing of software. (IATL & FCHTL)
- Test C - Integrated test of FCS functions essential to flight control, simulated dynamic input to sensors (open loop), all avionics essential to FCS (sensor, RACU, data bus, actuator, display, etc.) and other equipment sharing FCS data bus. (IATL, Section 10.6)
- Test D - Full mission integrated test facility (FMITF); GN&FCS functional and performance test of total software and hardware functioning; flight software verification; avionics should be complete in all areas sharing computers and data busses to insure thorough system data rate, priority and timing tests

2.13.2.2 Certification for First Horizontal Flight

- Flight control system (FCS) electrohydraulic dynamic test A completed
- FCS sensor-data bus-computer dynamic test B completed
- FCS functional/dynamic performance test C completed. Verify software/hardware for functions required for horizontal flight program; system dynamic stability and performance
- FCS dynamic stability analysis complete (horizontal flight)
- FCS software review by software review board

2.13.2.3 Certification for First Mated Flight

- FCS dynamic performance verification analysis complete
- FCS dynamic performance and software verification test D complete
- Guidance and navigation (G&N) system performance verification analysis complete
- G&N software verification test D complete
- GN&FCS software review by software review board

2.13.3 ANALYTICAL TECHNIQUES

Trajectory analysis for all mission phases, aborts and alternate missions will be conducted using six-degree-of-freedom computer programs. These programs have accurate models of vehicle and environmental characteristics, such as propulsion, aerodynamics, aerodynamic heat rate at various points on surface, atmospheric model, etc. The vehicle performance achieved with the design trajectories will be compared with the optimal trajectories computed from an existing trajectory optimization program.

Navigation and guidance system requirements and performance analysis will be accomplished using a variety of computer programs. Guidance technique evaluation will be done using six-degree-of-freedom programs, giving full interaction dynamics of guidance and control. Navigation error analysis will use existing statistical analysis programs, and Monte-Carlo techniques will be used to get final G&N accuracy verification. Guidance steering performance will be evaluated by comparison to the optimal trajectories.

Analysis of the flight dynamics and FCS stability and control will be accomplished using several computer programs. Flight simulation results will also be utilized. Six-degree-of-freedom and three-degree-of-freedom programs with detailed models of the FCS elements and digital electronics will be used, as appropriate.

The complete GN&FCS flight software algorithms will be developed and analyzed using Fortran models on the scientific computers. Analytic test conditions and software output functions will be generated for use in software/hardware verification tests C and D.

2.13.4 FACILITY REQUIREMENTS

- Flight Control/Hydraulic Test Laboratory (FCHTL)
  - Actuator inertia loading and local structural stiffness
  - Capability to perform limited six-degree-of-freedom flight simulation closed-loop with IMU, flight computer, RACU and data bus (FCHTL and IATL)

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- Full Mission Simulation Laboratory
  - Rendezvous and docking
  - Entry/transition
  - Landing approach
- Full Mission Integration Test Facility (FMITF)
  - Dedicated computational equipment
- Scientific computer facilities (See Section 12.0)
  - IBM 360-75, 67
  - IBM 1130

2.14 SIMULATION

The orbiter simulations discussed in this subsection provide for a two phase approach to evaluate pilot and vehicle capabilities to perform critical maneuvers and tasks; the first phase utilizing the existing Grumman simulation laboratory facilities and the second phase a dedicated orbiter facility. Preliminary design data will be developed from part task simulations, using existing Grumman general purpose facilities for the conceptual and design tradeoff studies impacting preliminary design review (PDR). A dedicated fixed base orbiter simulation facility will subsequently provide design verification data for critical design review (CDR), first horizontal flight (FHF), and first manned orbital flight (FMOF) (see subsection 10.6).

The orbiter simulation program, using the Grumman general purpose simulators and modified LM/Apollo simulators is directed toward man-in-the-loop aerodynamic validation of the airframe's handling/flying qualities and flight control system. In the initial phase the simulation program utilizes six DOF equations of motion in conjunction with the Grumman motion simulator and a first generation orbiter fixed-base simulator. The motion base simulator and the first generation orbiter fixed-base simulator will be used primarily for engineering part task evaluations of:

- Separation and insertion, and abort criteria studies
- Rendezvous and docking
- Entry and transition
- Approach and landing
- Cargo manipulation

The motion simulator has three-degrees-of-physical motion; translation in vertical heave, and rotations in roll and pitch which provide motion cues to the pilot. The Grumman motion simulator includes a visual out-the-window presentation which is a point light source visual display projected onto the rear of a flat screen.

For the fixed-base simulator, an external visual display system will provide the necessary real world scenes for the above part task engineering studies. These simulators will use Grumman/LM/Apollo equipment such as:

- Computers - IBM 7094 - 1800, REAC 500; computer requirements are defined in Section 10.6
- Computer interface equipment - Adage 770
- Image generation equipments - NIKE-AJAX, RECOSY

The results of Phase I part tasks simulations will be applied to the development of the more detailed simulator equipments which will be part of the dedicated orbiter systems integration, simulation, and test complex (Reference section 10.6). The operational philosophy of providing separate but simultaneous capability for each major portion of a simulation and test complex, as was conducted in the LM, F-14 and A-6 programs, is being followed for orbiter. Additionally, real time simulation evaluation capability using these facilities is always maintained throughout the orbiter design and development.

The accompanying logic diagram (Fig. 2.14-1) depicts simulation activities from a user viewpoint while subsection 10.6 covers the development of simulator facilities and their integration with the flight controls hydraulic test laboratory and the integrated avionics test laboratory to form the full mission integrated test facility.

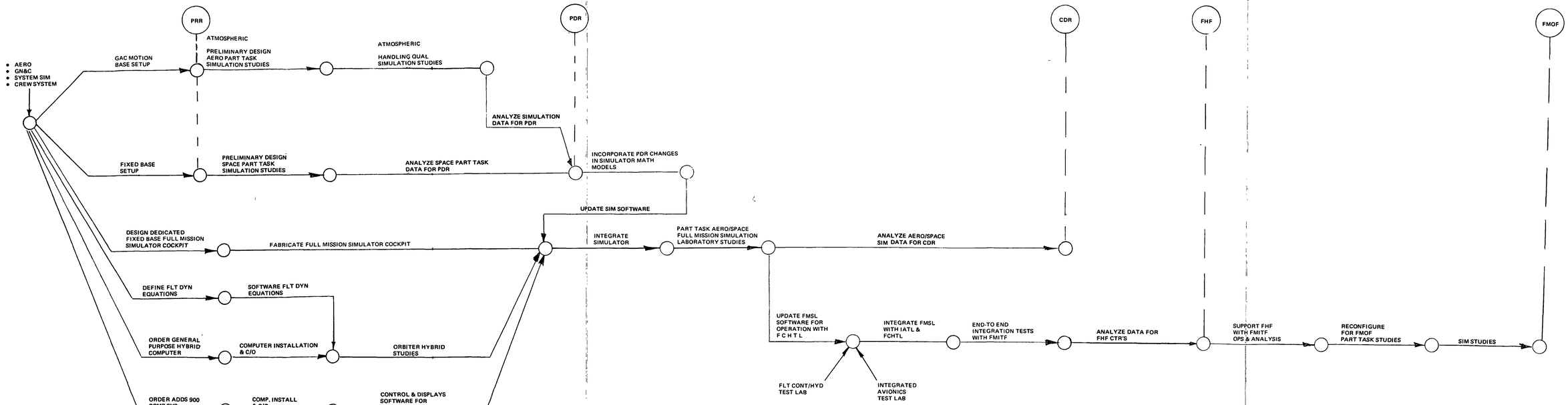

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Fig. 2.14-1 Simulation Logic Network

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2.15 QUALITY ASSURANCE ENGINEERING

2.15.1 INTRODUCTION

One of the objectives of the Engineering and Development Plan is to minimize the risks associated with the space shuttle development. Towards this goal, the quality assurance program is being developed with an emphasis on the formulative design and engineering aspects of the DDT&E phase as well as the subsequent production phases.

This subsection is limited to a summary of selected quality requirements and a salient description of the quality program approach as it relates to the design and development control aspects of the program. The detailed requirements, criteria and approach to quality are presented in the Space Shuttle Orbiter Quality Assurance Plan (552-43RP-6).

Quality assurance provisions have also been included in the ASSC System Definition Handbook and a summary of related activity is presented in this Phase A Report.

2.15.2 REQUIREMENTS

In line with the program the objective of developing an economical space shuttle system, our goal is to arrive at an engineered design which will result in the required quality level at the lowest possible cost.

The quality assurance program plan established for the orbiter is responsive to the intent of NHB 5300.4(1B) entitled "Quality Program Provisions for Aeronautical and Space System Contractors", as interpreted in the requirements of the applicable NASA statement of work. The plan also reflects elements of special interest, innovations and projected areas of cost reduction.

2.15.3 QUALITY ASPECTS OF ENGINEERING TRADEOFF STUDIES

Throughout the Alternate Space Shuttle Concepts (ASSC) studies, experienced quality engineers (QE's) have worked with design engineers to assure adequate consideration of quality aspects of applicable engineering tradeoff studies. A checklist of 16 typical considerations used during these evaluations is included with the quality assurance provisions

of the System Definition Handbook. Results of these evaluations have been documented in respective trade study reports.

Where additional tradeoff studies are required during the design and development phases, coordinated quality engineering participation will continue to take place.

2.15.4 QUALITY CRITERIA FOR DESIGN REVIEWS

To benefit from the experience derived from earlier hardware programs such as the LM, OAO and F-14, the shuttle design review program includes a detailed assessment of quality criteria. These criteria will be evaluated prior to and during each shuttle program milestone review (e.g., PRR, IDR's and PDR) as well as respective seller design reviews.

The procedure to be employed for quality engineering participation at design review meetings has been documented and implemented in a Grumman quality instruction (QI). A summary of 17 quality criteria for consideration during design reviews has also been presented in the System Definition Handbook's quality assurance provisions.

2.15.5 CLASSIFICATION OF CHARACTERISTICS

For those characteristics of parts where special manufacturing and inspection attention is extremely important, a system of classification of characteristics on engineering drawings will be implemented. Appropriate items or areas on drawings will be identified in a manner consistent with the intent of Grumman specification No. SP-G-022 from which the following definitions have been extracted:

- Class C - Critical: A critical item is one that, if discrepant, could result in a hazardous or unsafe condition for individuals using or maintaining the product; or that could result in the loss of an aircraft
- Class F - Fatigue Critical: A fatigue critical area is one where the stress level is sufficiently high that if a defect occurs in the area, it can result in a fatigue failure which may result in the loss of an aircraft

Classifications of characteristics will thus be used as a guide for inspection planning purposes to assure proper emphasis and identification of special manufacturing/inspection considerations.

2.15.6 NONDESTRUCTIVE EVALUATION

To verify the integrity of the shuttle structure, tankage and thermal protection system, a system of nondestructive evaluation (NDE) techniques will be employed during the vehicle fabrication, flight test, and operations phases. The System Definition Handbook contains a summary (matrix) of NDE requirements and a compilation of capability and limitations for the four most adaptable and available techniques, i.e., fluorescent penetrant, radiography, ultrasonics and eddy current.

A comprehensive trade study has been performed on the various applications of NDE to the shuttle configurations; details are contained in the Nondestructive Evaluation Trade Study Report. Additional information is available in the orbiter quality assurance plan, the Grumman nondestructive test manual and the NDE design guide currently being prepared.

2.15.7 VALUE ENGINEERING/PRODUCIBILITY

Quality assurance is an active member of the Value Engineering/Producibility team, which also consists of representatives of other functional departments, e.g., engineering, manufacturing, procurement and operations. These teams, under the cognizance of a value analysis manger, evaluate product designs and specifications for producibility and cost control as described in subsection 2.16.

2.15.8 QUALITY ASSURANCE PLAN

The orbiter quality assurance plan contains details for implementing the quality system procedures. It consists of the following sections:

- Introduction
- Management and planning
- Design and development controls/identification and data retrieval

- Procurement controls
- Fabrication controls/inspection and test
- Nonconforming material
- Other quality program elements

Appendices are also included therein for pertinent supplementary information including:

- A - KSC Quality assurance outline for shuttle operations
- B - Quality program documentation
- C - Frequently used shuttle quality assurance abbreviations and acronyms
- D - Relationship of shuttle functional program plans/documentation to quality assurance plan
- E - Selected skills/crafts requiring qualified personnel
- F - Contamination control document

2.15.9 QUALITY ASSURANCE ORGANIZATION

The orbiter quality assurance program elements are structured in a manner consistent with the functional organization and compatible with work breakdown structure (WBS) requirements. Details relating to element responsibility are described in the orbiter quality assurance plan.

2.15.10 ENGINEERING AND QUALITY ASSURANCE INTERFACES

Typical areas of interface between engineering and quality assurance are summarized below. They are described in further detail elsewhere in this plan as well as in the orbiter quality assurance plan.

- Management and Planning
  - Quality data and reporting
  - Training requirements

- Design and Development Controls/Identification and Data Retrieval
  - Quality support of design reviews
  - Change control and effectivity
  - Configuration management
  - Identification methods and control
  - Documentation
- Procurement Control
  - Selection of procurement sources
  - Procurement requirements/documentation
  - Technical support/process control
- Fabrication Controls/Inspection and Test
  - Cleanliness levels/contamination control
  - Process control
  - Nondestructive evaluation techniques
  - Workmanship standards
  - Test specifications and procedures
  - Qualification of hardware
- Nonconforming Material
  - Material review system
  - Supplier material review
  - Failure reporting/analysis and closeout
  - Waiver requests
  - Documentation

- Other Quality Program Elements
  - Evaluation of measurement standards and equipment
  - Measurement processes
  - Acceptance data package
  - Handling, storage, preservation, packaging and shipping

2.16 VALUE ENGINEERING/PRODUCIBILITY

2.16.1 INTRODUCTION

The orbiter value engineering/producibility objective is to reduce total program cost. To minimize cost there must be effective interfacing of engineering, manufacturing, procurement and operations activities. An integrated system for value engineering/producibility interfacing has been initiated for the development and operational phase of the orbiter program. It is a modified version of the F-14 producibility function, already tested and proven successful. The system is designed for cost avoidance and will be implemented during all phases of development.

The value engineering/producibility effort is specifically directed toward elimination or modification of tasks that are not necessary to produce required performance, quality, reliability, or interchangeability. Functional analyses will be accomplished by placing small teams in all areas of product design. These teams will be composed of experts from engineering, manufacturing, procurement and operations. Teams will be coordinated by a value engineering/producibility manager who reports directly to the program office, and who must approve major layouts and selected specifications for cost prior to their release.

It will be the responsibility of the team members to familiarize themselves with design requirements as they develop, to check these requirements against the task imposed on the functional department they represent, and to aid the design groups in controlling the costs of the end product or system for that department. These teams will therefore initiate and participate in tradeoff studies within and between departments until a balanced compromise between performance objectives and cost is achieved.

The end product of each team is a definitive producibility plan for each end article or system. This plan will be developed step by step as the design evolves, ensuring that the plan and the design are compatible and within projected cost prior to design configuration freeze. When the plan is completed and acceptable to the team, it will be forwarded to the

program office for approval. Upon approval and acceptance by the program director, the plan will be published and distributed to the functional departments as program direction.

2.16.2 ORGANIZATION

The function of the plan is to provide communication between engineering and all other orbiter organizational elements. Fig. 2.16-1 shows this organization.

The value engineering/producibility manager and the three coordinators under him are part of the program staff. The coordinators will staff and manage the Teams.

The value engineering/producibility teams are comprised of a small number of members representing all functional departments on the program.

2.16.3 APPROACH

For the orbiter which is an extremely low-production program, engineering and development account by far for the greatest portion of total program cost.

As shown in Fig. 2.16-2, the potential savings from value engineering/producibility are much greater in the E&D stage. To realize these savings our efforts concentrate on cost avoidance in:

- Engineering
- Tooling
- Manufacturing
- Maintenance and operations requirements
- Development testing
- Program operations

Our approach is to:

- Exploit low cost alternate designs early in the program
- Identify areas having cost reduction potential with assistance of program personnel
- Maintain follow-up to ensure implementation of proposals for maximum cost reduction

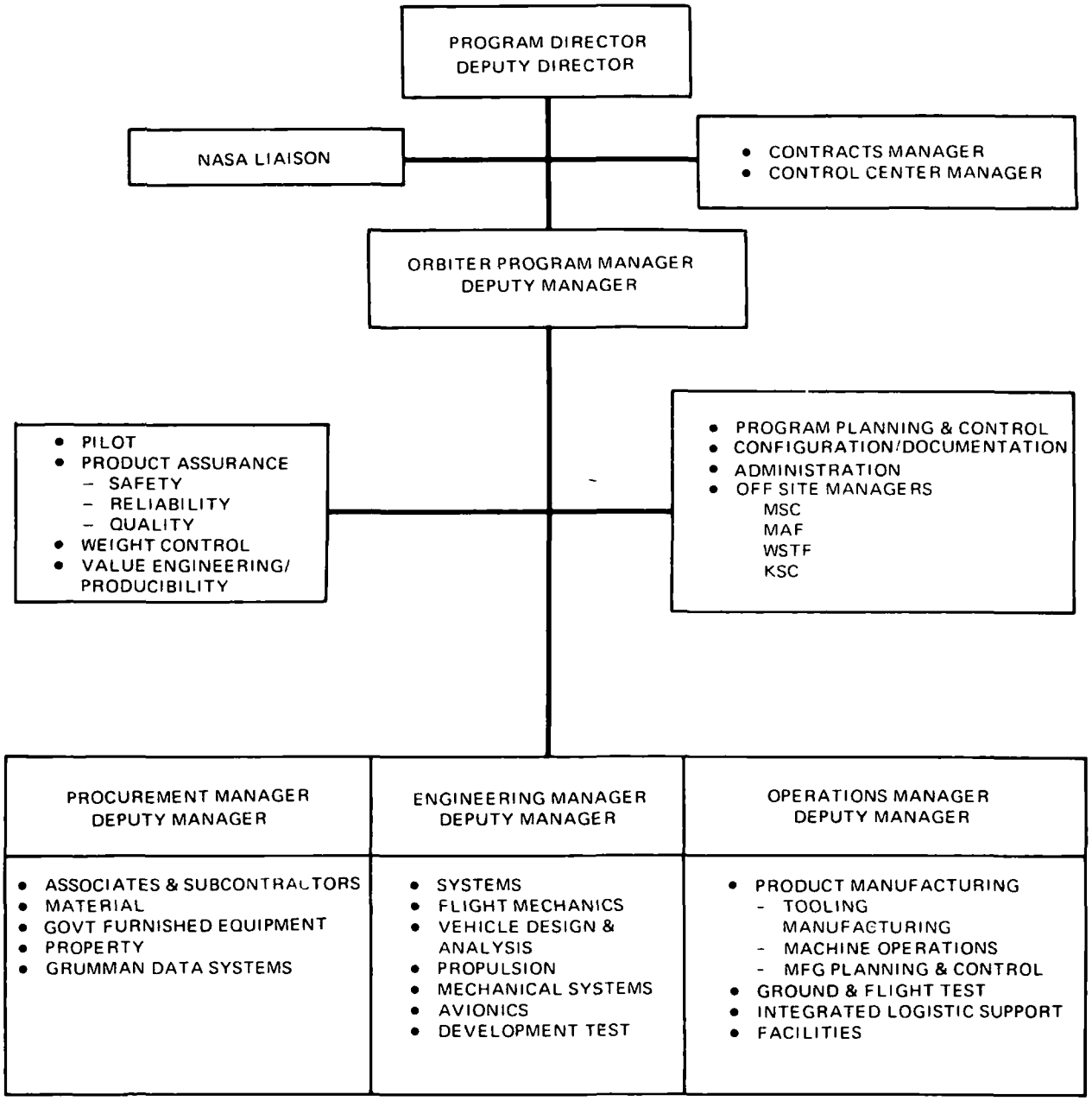

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Fig. 2.16-1 Orbiter Program Organization

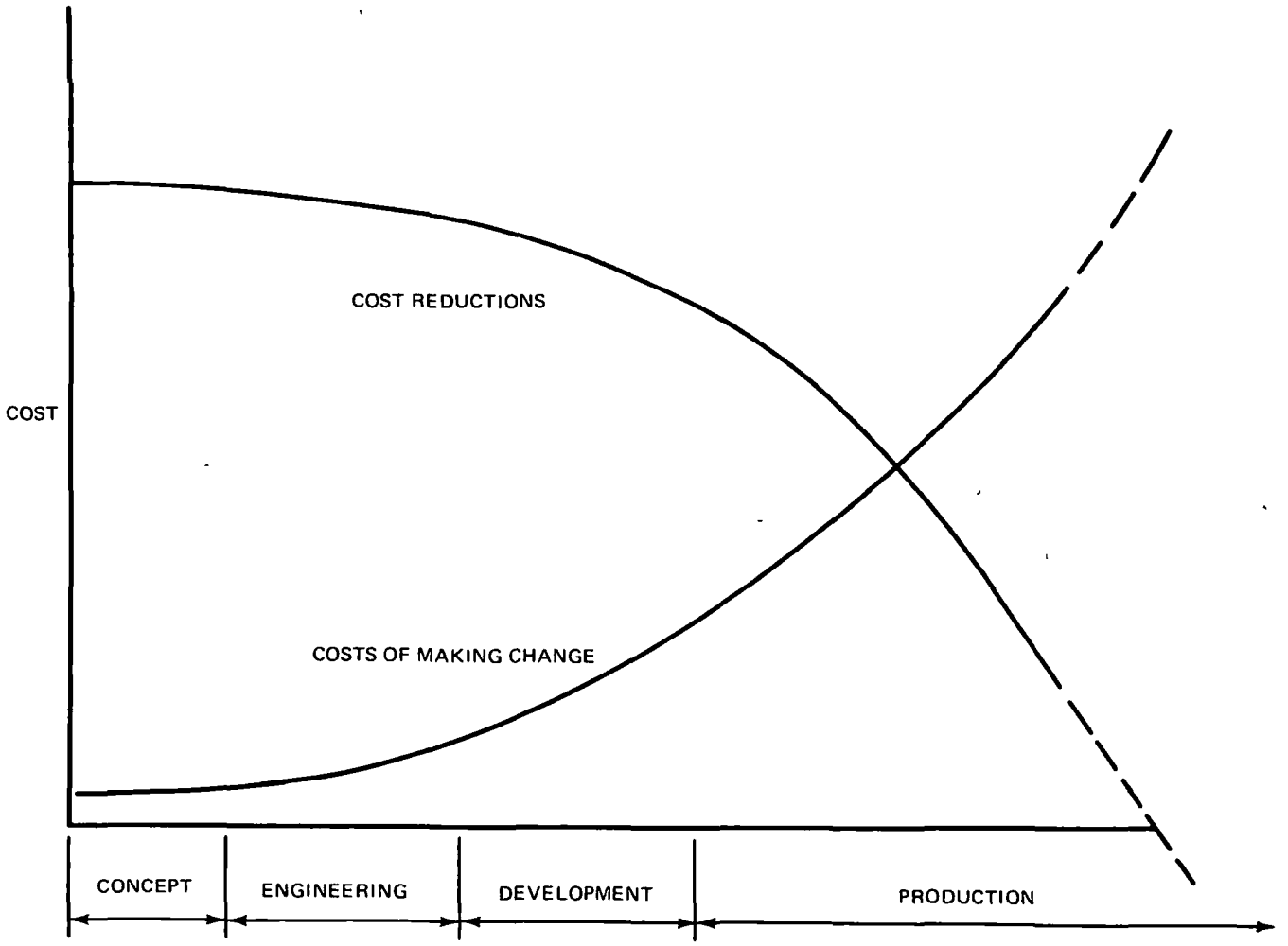


Fig. 2.16-2 Advantages of Early Value Engineering/Producibility

- Provide available cost data to designers and decision making personnel
- Review specifications and contractual requirements to eliminate or reduce unnecessary costs

2.16.4 COST TARGET SYSTEM

The cost target system used in the design stage is comparable to the weight bogie system. The need for establishing and controlling cost targets at prescribed levels, and the many advantages to be derived by the use of this system, are clear. As projected costs approach target costs, corrective action is initiated to meet or better the original cost targets.

The cost target system for structural components, systems, subsystems and test activity will control cost at level (6) of the work breakdown structure. To achieve this goal, some Level (7) items will be tracked for cost of component parts, assemblies, and subassemblies. These items will be identified at their proper level in the producibility plan as it develops and will be tracked by this identification.

Test programs will be monitored similarly to avoid cost overruns.

The teams obtain information for development of cost targets from functional departments for major design packages and components. During the course of the design, engineering will submit partially completed layouts to the value engineering/producibility group, for cost analysis and comparison with the original target. When the analysis indicates that the cost target will be exceeded, the cognizant engineer will be alerted, cost saving suggestions will be evaluated and redesign will be initiated to meet the target. The effect of changes on cost targets will be continually examined and monitored. Fig. 2.16-3 is a flow chart of the procedure.

2.16.5 CURRENT PARTICIPATION

Starting with the earliest Grumman orbiter feasibility investigations and preliminary design, the value engineering/producibility group has actively pursued the incorporation of cost avoidance producibility features in the design. This activity will continue only as lon as the cost savings it realizes can more than pay its way.

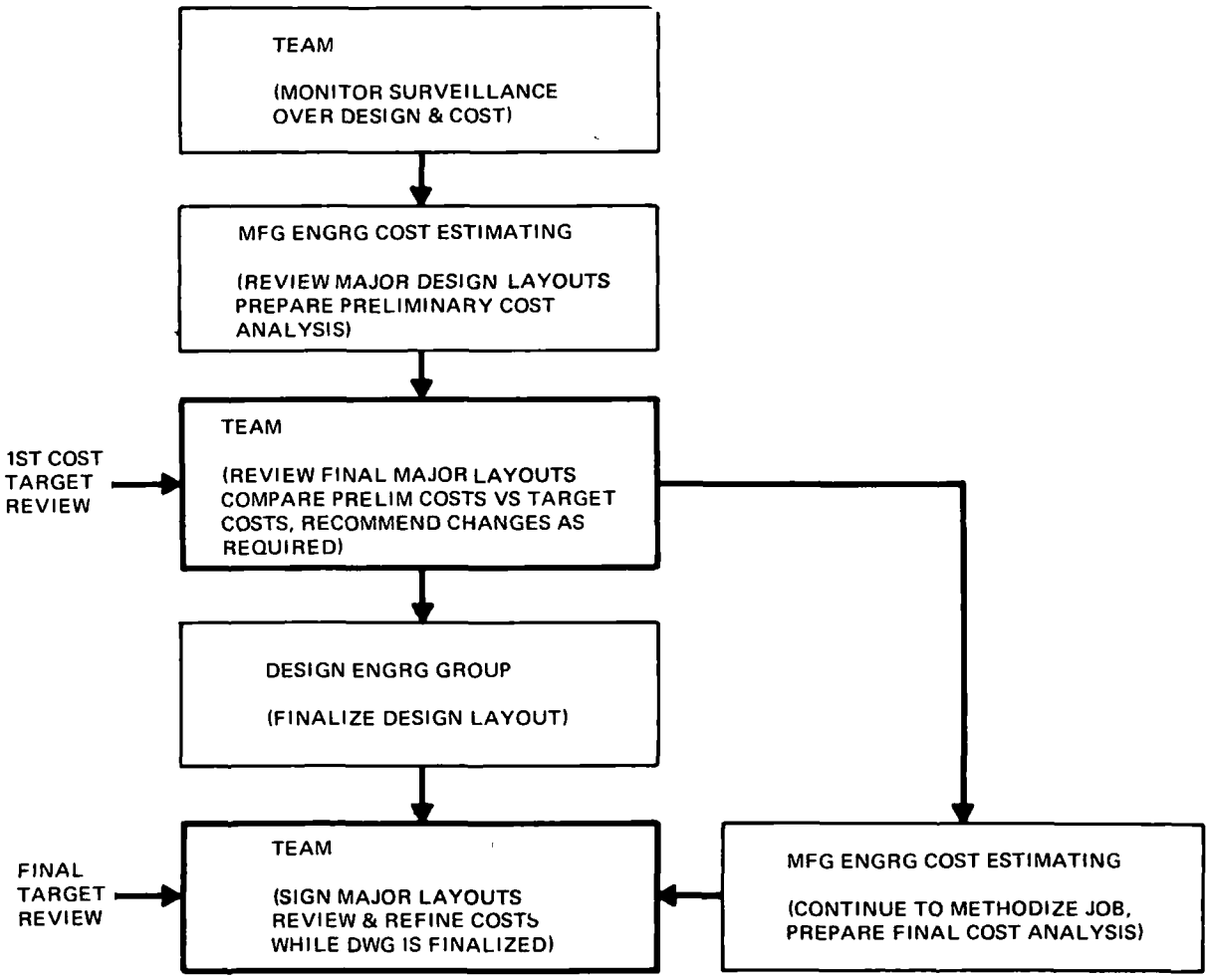


Fig. 2.16-3 How VE/Producibility Teams Operate

H-33 design features in which value engineering/producibility has been a strong influence are:

- Floating Tank Installation - Configuration lightest and cheapest
- Constant Section Mid-Module - Simplified manufacturing
- Flat or Warped Wing Skins - Elimination of double curvature structural wing skin reduces cost
- Unitized Crew Compartments - Improves schedule and reduces cost
- Expendable External LH_2 Tank - Simplifies manufacturing
- Wire Termination System - Each circular wire end is terminated in an environmentally sealed crimp-type contact. Environmentally sealed junction blocks virtually eliminate the need for junction boxes
- Signal Multiplexing - The advertised benefits of this design and manufacturing approach are:
  - Weight Saving
  - Lower production cost
  - Design flexibility
  - Adaptable to on board checkout

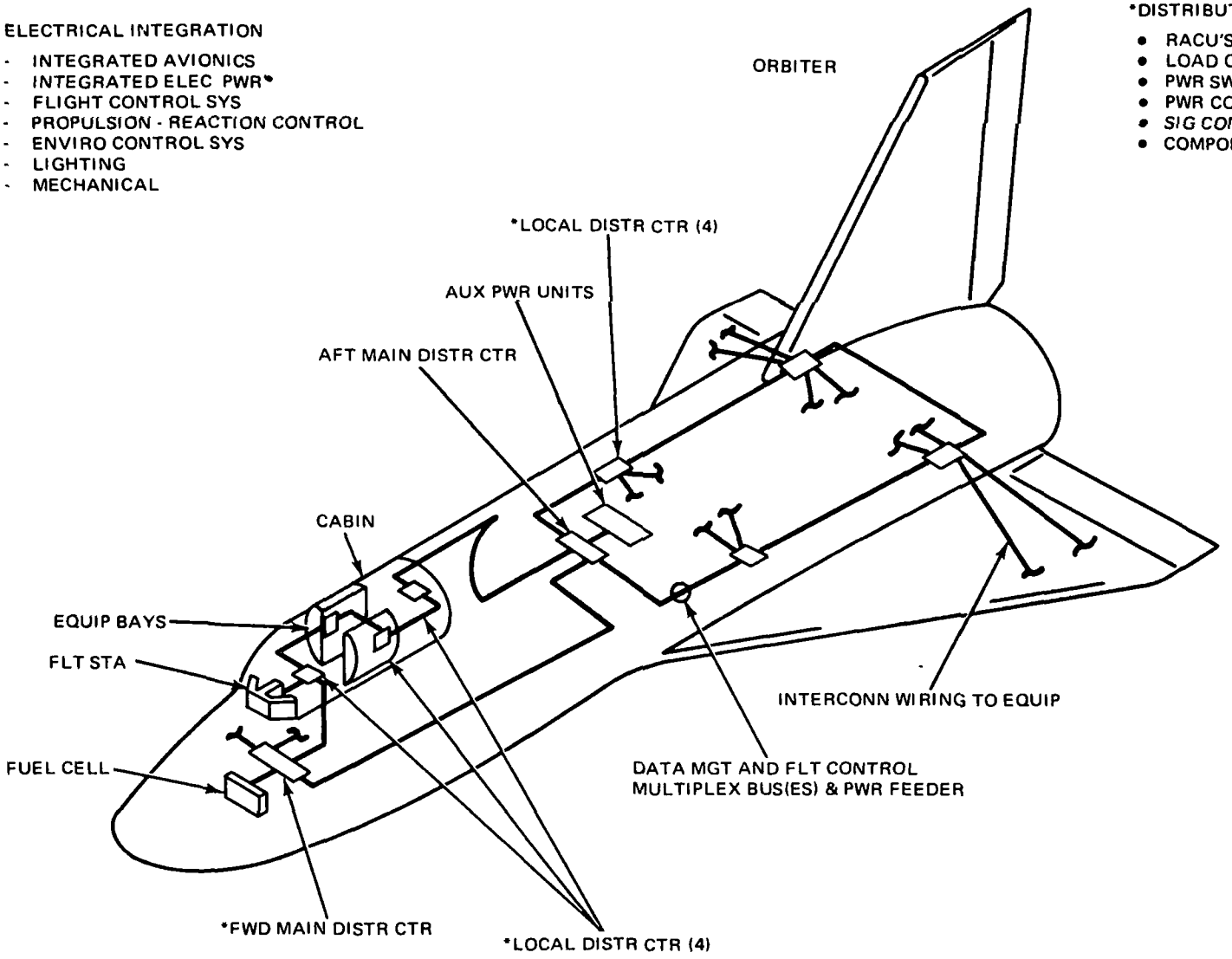
  Serious consideration is being given to this approach and studies are continuing. Further evaluation is necessary to prove the cost effectiveness and readiness of the art of multiplexing to be real (see Fig. 2.16-4.)
- Cabling System - The intra-vehicle cabling of the orbiter for all the various electrical and electronic equipments requires a great amount of wire. The design approach for interconnecting equipment features wire crimp/weld terminations for harnesses using cable junction points or mated connectors for system distribution, depending on the specific cost analysis

ELECTRICAL INTEGRATION

- INTEGRATED AVIONICS
- INTEGRATED ELEC PWR*
- FLIGHT CONTROL SYS
- PROPULSION - REACTION CONTROL
- ENVIRO CONTROL SYS
- LIGHTING
- MECHANICAL

*DISTRIBUTION CTRS CONTAIN

- RACU'S
- LOAD CONTROLLERS
- PWR SWITCHING
- PWR CONDITIONING
- *SIG CONDITIONING*
- COMPONENT THERMAL CONTROL



SKETCH INDICATES THE METHODOLOGY OF EQUIPMENT PACKAGING & INSTALLATION

- AVIONICS IN PRESSURIZED & MAINTAINABLE CABIN
- MULTIPLEX & PWR FEED TERMINALS AT DISTR CENTERS
- DISTR CTR STRATEGICALLY LOCATED FOR REGIONAL CONTROL
- *MODULAR PACKAGING*

GRUMMAN BOEING

E-108X

Fig. 2.16-4 Signal Multiplexing

- NASA/Grumman Space Packaging System - Grumman and NASA funded studies indicate that a modular assembly, line replaceable unit (LRU) approach will be employed for new equipment designs. The system being developed will be used to provide high reliability and maintainability at reduced cost. This is accomplished through the use of standardized modules mounted to the equipment rack or enclosed in a box. Should a failure occur, these modules are readily replaceable and can be repaired at a bench level. Modules will be held in place by quick-turn fasteners at appropriate locations and provide an efficient module-to-cold-rail thermal interface.

2.16.6 SCHEDULE

Phase C/D value engineering/producibility activities are shown in Fig. 2.16-5.

2.16.7 AIRFRAME TEAM

For the reasons mentioned earlier, primary emphasis is on the E&D phase. Therefore, engineering designs, specifications and test plans will be reviewed for their effect on tooling, test article fabrication, and test operations, as well as production of the vehicle.

Value engineering/producibility teams will be assigned to major structural assemblies. The teams will initiate tradeoff studies, identify value engineering/producibility guidelines (which will guide detailed design), influence product engineering as necessary to design producibility into the product and, most important, will develop a producibility plan.

The producibility plan serves the purpose of informing functional departments concurrently of the vehicle structural configuration, the test operation requirements, and the materials, manufacturing equipment, fixtures, facilities and handling equipment required to fabricate the airframe. This plan, completed early in the design phase, is then used as the directory for advanced planning and scheduling.

The airframe producibility plan will include:

- Structural breakdowns that identify major assemblies and subassemblies and locate structural and systems interfaces
- A manufacturing plan that describes the fabrication of sheet metal and machined parts, subassemblies and major assemblies

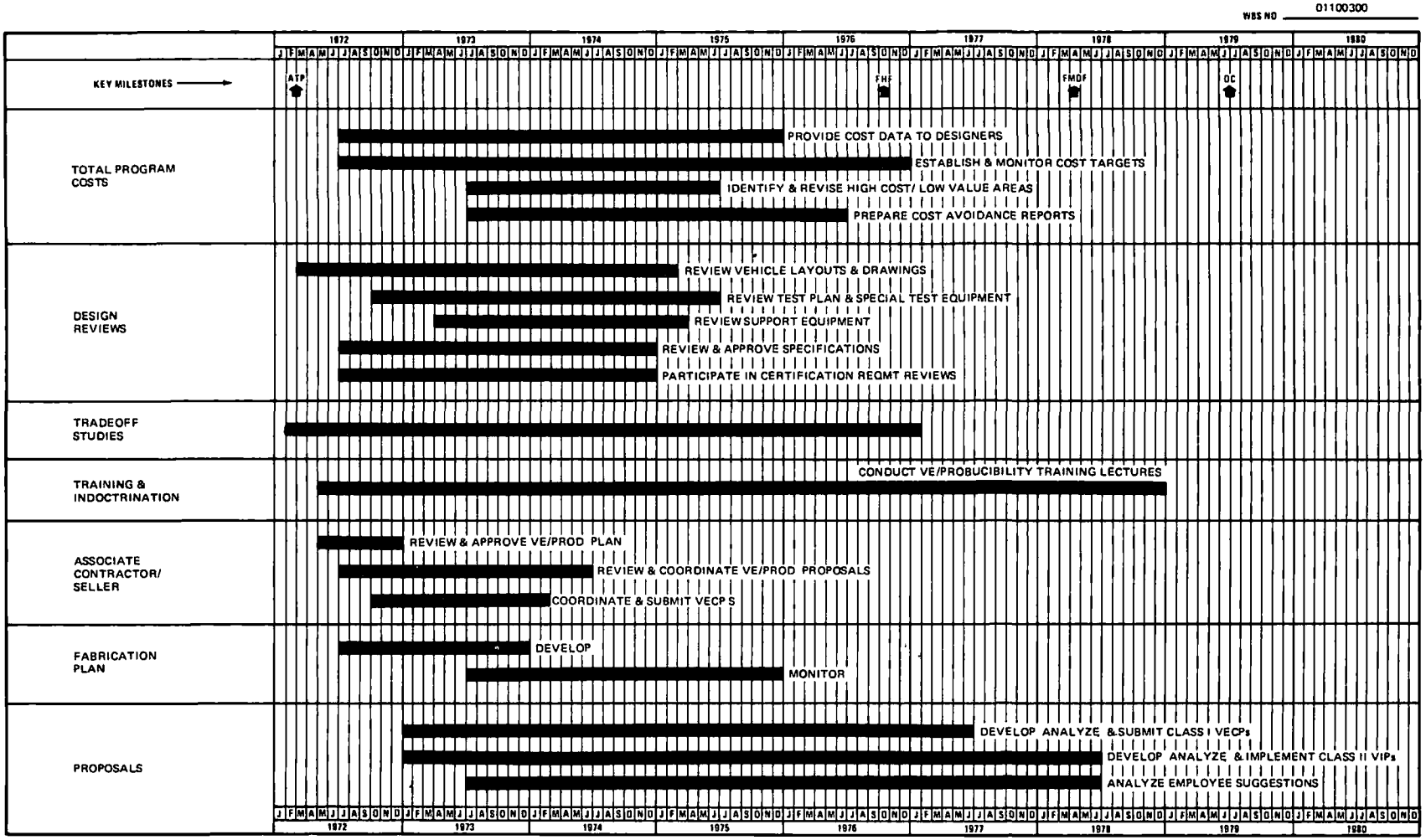


Fig. 2.16-5 VE/Producibility Schedule

- Manufacturing flow plans that describe the flow time and manpower loading requirements for fabrication of assemblies
- Critical material lists that identify parts and raw materials with respect to cost and availability of material and dictates the use of conventional, precision or no-draft forgings and castings in order to effect maximum economy

The limited number of vehicles to be produced requires that the major engineering layouts be reviewed to minimize production tooling costs. The airframe teams will assure the following:

- Assembly fixtures will be designed for multipurpose tooling where possible
- Assembly tooling will be limited to those areas requiring interface accuracies
- A high percentage of shear panel commonality to limit tooling requirements
- A high percentage of flat or wrapped straight - line element titanium shear panels to allow for low cost cold forming techniques
- Commonality of titanium parts, to make hot form tools cost effective

Designs requiring expensive tooling approaches will be challenged, and tradeoff studies accomplished to determine if corrective action is required.

Since the test programs represent a large cost to the program the team will participate in the Certification Requirements review described in subsection 2.5 to insure that tradeoffs are adequately evaluated. In those certification areas which require airframe test, the team will implement and monitor a test cost target as outlined in subsection 2.16.4.

2.16.8 SUBSYSTEM TEAM

The subsystem team ensures that the overall cost of subsystem components, materials, tooling, fabrication, and test is within the previously established cost target.

Tradeoff studies at proposal concept and continuing throughout the design phase to ascertain minimum product cost are conducted. Results of individual tradeoffs are incorporated in the subsystem design.

Specific preplanning analysis employing the use of the crew and equipment lines mockup will optimize the hard and soft lines development. A computerized electronic design automation (EDA) program will be used during orbiter development to collect preliminary subsystem interconnect wiring for harness development.

EDA information gives immediate visibility to:

- Individual harness cost
- Material requirements
- Tool requirement
- Configuration
- Methodization/preplan approach

We are now conducting tradeoff studies to determine the best connection techniques for fluid lines. Items under study include cryogenic, dynatube fittings, titanium vs steel tubing, and welded vs brazed joints.

The subsystem team's production plans will include:

- Assembly and subassembly breakdowns for each subsystem and identification of the major interface requirements with other subsystems
- Manufacturing Plan that will consist of a preplan analysis describing the fabrication, buildup and installation of the subsystem, and identifying test and test equipment required to support the subsystem
- Installation and test plan describing an installation sequence to ensure that the subsystem components, and tests are available and test conducted at the optimum production stage

2.16.9 GROUND SUPPORT SYSTEM TEAM

This team's responsibility is to ensure that the design, development, manufacturing and test of ground support system equipment is accomplished at low cost.

Specific illustrations:

- A computerized equipment inventory system is employed throughout the design effort
- CAPER, a computerized calibration equipment recall system, is interrogated to avoid unnecessary procurement of already available, commercial type equipment
- Control of sellers to assure on time delivery of equipment at low cost
- EDA (electronic design automation) provides support equipment electrical interface information
- Some active functional tests will be performed automatically. This will eliminate the need for special test equipment for some subsystems
- Automatic calibration will be introduced in the microwave area
- On-site or in-place performance verification (PV) will be substituted for much of the conventional "remove and calibrate" technique

2.16.10 SPECIFICATIONS AND REQUIREMENTS

Functional value analysis of specifications and requirements provides management with cost reduction in engineering and development. The current estimate indicates that there will be over 2700 specifications on the space shuttle, compared with approximately 1800 on LM and 1000 on F-14.

The object of the value engineering/producibility effort in this area is directed to elimination of unnecessary specifications, to minimize the actual number generated and to monitor the necessary specifications to insure that the requirements are not overstated. Upon identification of excessive or unnecessary requirements, cost savings are estimated and value engineering change proposals (VECP's) are submitted to eliminate or reduce the requirement.

2.16.11 TRAINING AND INDOCTRINATION

Training in value engineering and producibility techniques and principles is directed to selected program personnel, designers, and engineers through short seminars.

2.16.12 ASSOCIATE CONTRACTORS AND SUBCONTRACTORS

To keep costs under control, our objectives are shared by our Associate Contractors. We exchange cost avoidance information and assistance and extend value engineering incentive sharing clauses to our Associate Contractors. They submit VECP's to NASA via Grumman for coordination and cross-pollination of ideas.

Subcontractor/seller participation in the program is encouraged in the early phases to obtain cost reductions through the following actions:

- Grumman assists our major subcontractors/sellers in developing and completing their value engineering proposals
- Class I Seller VECP's are processed in-house and documented
- Suppliers of major assemblies, equipment, and components are required to furnish a program plan and reports of their efforts
- Grumman includes appropriate value engineering incentive sharing arrangements in any subcontract of such a size and nature as to offer reasonable likelihood of cost reductions

2.17 MATERIALS AND PROCESSES

2.17.1 INTRODUCTION

A materials and processes engineering development plan will be established to cover the standardization, selection, application, qualification, processing and control of materials, parts and components to ensure crew safety and operational integrity of the vehicle. The plan shall encompass the design and test development, hardware acquisition, qualification, acceptance and flight operational phases of the orbiter vehicle as well as ground support equipment (GSE) and other interfacing components such as flight test instrumentation.

2.17.2 KEY DEVELOPMENT ISSUES

In support of the design, development and manufacturing phase of the orbiter and related subsystems, material and processes development testing will be performed to evaluate, characterize, and select suitable materials and processes that satisfy the environmental requirements and vehicle mission life. Key areas to be investigated are:

- Fracture mechanics testing of candidate materials for tank structure
- Evaluation of external insulation (EI) to assess its capability for vehicle mission cyclic loading (both structural and thermal)
- Evaluation of carbon/carbon oxidation inhibited material to assess its reuse criteria
- Evaluation of a backup material for the carbon/carbon system
- Evaluation of corrosion control coatings and systems to assess their effectiveness when subjected to the mission environmental conditions
- Fatigue properties of structural and TPS materials at elevated temperatures

- Development and evaluation of high temperature radomes and antenna windows
- Physical and thermal stability characteristics of TPS internal insulation materials for cyclic thermal exposure and environmental loading conditions
- Compatibility of packaging materials with TPS internal insulation materials at higher temperatures
- Performance stability of thermal control coatings when exposed to cyclic environment simulating launch heating, earth orbit exposure and reentry heating
- The ability of seals, sealants, lubricants, hydraulic fluids, and grease materials to meet mission requirements and the compatibility of these materials with dissimilar materials
- Development and evaluation of cabin glazing materials and coatings
- Optimization and evaluation of welding techniques, verification of mechanical properties, and establish nondestructive evaluation (NDE) for quality control
- Flammability, odor, toxicity, and outgassing characteristics of materials. Materials that have been tested and found acceptable for use in oxygen at low pressure will not be retested
- Evaluation of high temperature bearings

Tasks to be performed in support of design and manufacturing are:

- Provide producibility information on metallic materials, particularly regarding such processes as brazing, welding, heat-treating, forming, and flame-spraying
- Train and qualify welding and brazing operators
- Provide technical assistance to design groups on all non-metallic materials including composites
- Provide technical direction for design and application of corrosion protection systems

- Provide technical guidance and approval of the design application of materials used in the vehicle
- Provide laboratory support to systems engineering in the analysis of test failures
- Provide support in the operations phase for:
  - Material usage control
  - TPS refurbishment
  - Post-flight reuse analysis of materials
  - Support of NDT inspection techniques

2.17.2.1 Inputs Required

Environmental and performance requirements for the candidate materials must be known.

2.17.2.2 Activities and Necessary Sequence

Activities and necessary sequences are shown in the Logic Network (Fig. 2.17-1).

2.17.2.3 Outputs to Other WBS Items

The materials and processes WBS interfaces with vehicle design, structural analysis, manufacturing, quality control, reliability, vendors, and operations WBS.

2.17.3 COMMONALITY CANDIDATES

Materials and processes data developed at Grumman Aerospace and by the aerospace industry will be used as applicable. Results of NASA Space Shuttle Supporting Technology Programs will be used to avoid duplication of test programs. Booster vehicle materials and processes technology programs will be employed as applicable.

TABLE 2.17-1 FACILITY REQUIREMENTS LIST

Title and Description	New	Exist.	Contr.	Gov.
Laboratory facilities currently under the cognizance of the M&P Department will be used to support the program		●	●	
NASA test facilities will be used to augment Grumman facilities to test materials for toxicity and flammability		●		●

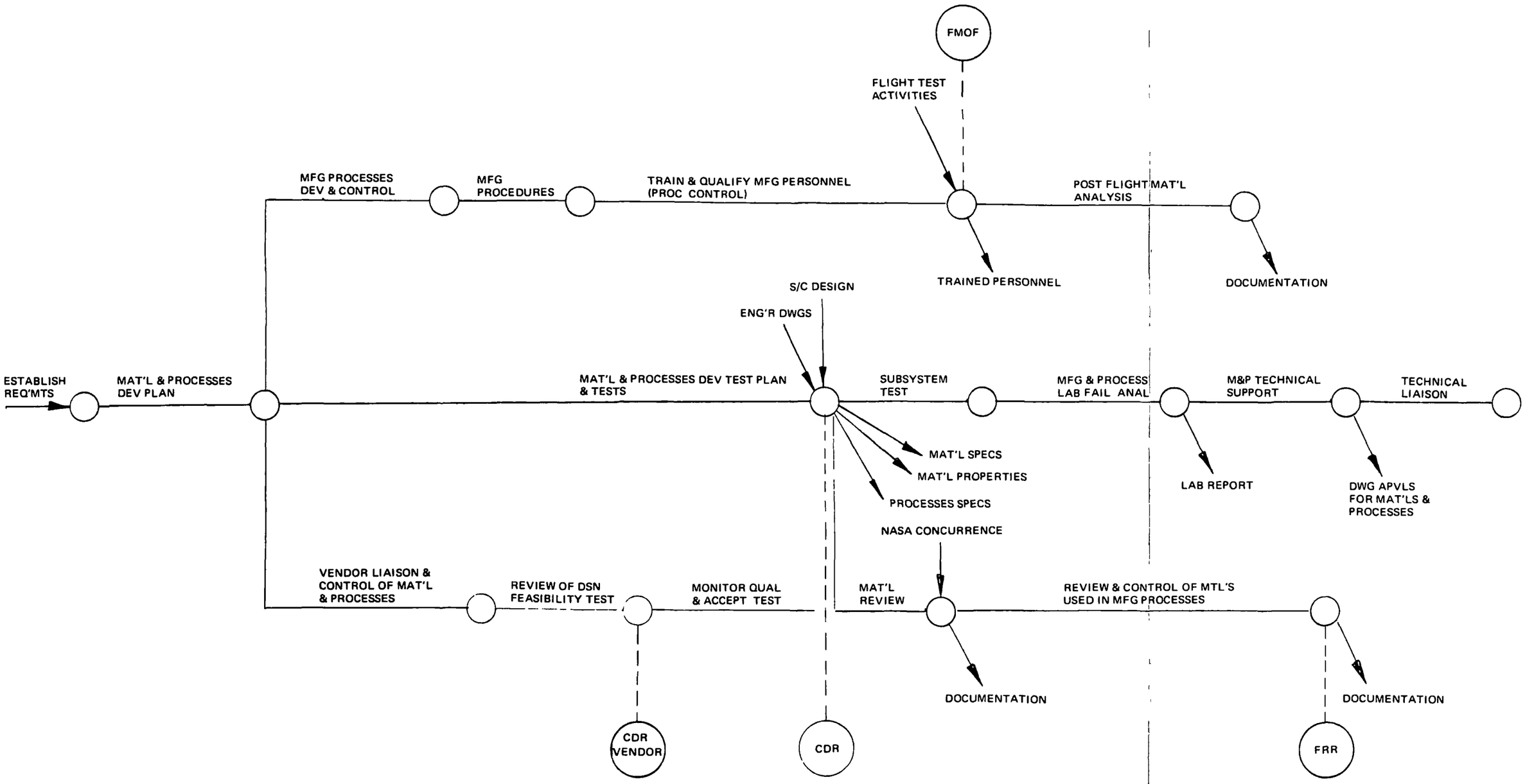


Fig. 2.17-1 Materials and Processes Logic Network

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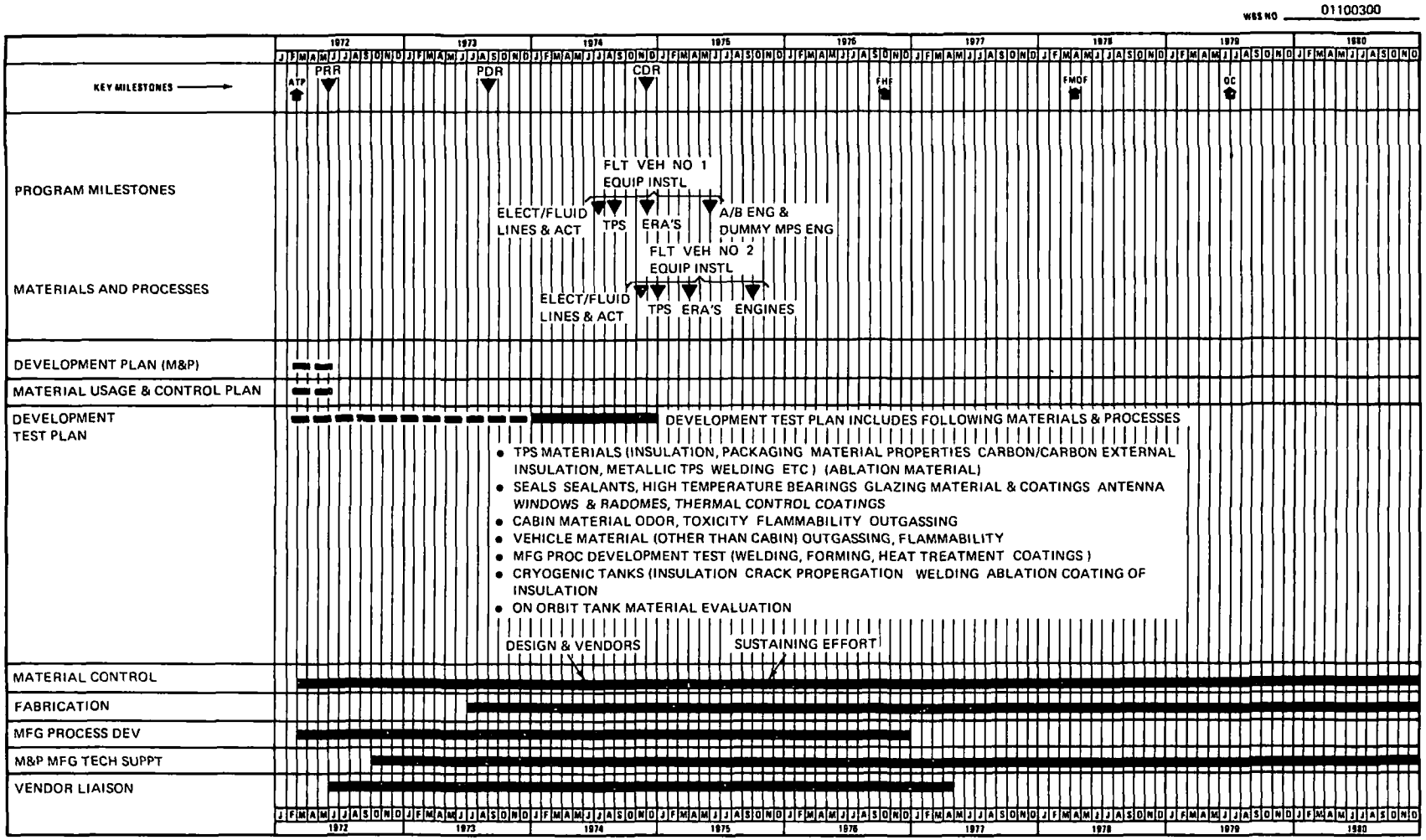

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Fig. 2.17-2 Material and Processes Schedule

2.18 ELECTROMAGNETIC CONTROL

2.18.1 OBJECTIVES

The major goal of the electromagnetic compatibility (EMC) group is to eliminate/minimize electromagnetic interference as applied to the orbiter design. Included within the EMC effort are activities covering lightning, static charging, rf hazards to personnel, fuel and electro-explosive devices. These EMC efforts, which will be described in a control plan, cover four areas:

- Vehicle Design - Bonding, lightning, vehicle fabrication, equipment and wiring installation
- System Analysis - Generate EMC requirements and control plan. Predict problems, propose solutions, conduct tradeoffs
- System Test - Establish facilities, generate test plans, perform EMC tests, support all other testing
- Subsystem - Generate and monitor sellers EMC efforts and implement interface control documents

The sequence of these major EMC efforts is shown in the engineering and development schedule, Fig. 2.18-1.

The EMC program blends the generic EMC skills, requirements and facilities, such as used on the Grumman LM spacecraft and F-14A aircraft, to solve the unique EMC problems of the orbiter. These unique problems include:

- Preventing safety hazards, unacceptable damage or loss of orbiter due to lightning strikes to exterior non-conductive vehicle surfaces - This problem has been solved for the F-14A boron horizontal stabilizer. Applicability of that approach to all orbiter environments requires further analysis

- Limitations of the orbiters' system EMC test program - The large size of the vehicle imposes relatively large costs if testing must be done in an environmentally clean, shielded anechoic hangar
- Attaining realistic funding and scheduling for EMC - The possibility of limiting system testing on a complete vehicle mandates tougher design constraints and more testing of all electrical/electronic equipment at a subsystem level as well as tighter controls for assuring electrical bonding and wiring separation on the vehicle
- Limited EMC information on multiplexing systems - The possibility of cross coupling between multiplexed subsystems coupled with the limited EMC technology in this area necessitates further study

Solutions to these unique EMC problems must be established early in Phase C/D and used as an input to the EMC control plan. A complete EMC logic and constraint network is depicted in Fig. 2.18-2, of which the major efforts to note are:

- EMC specifications - Subsystems will be procured using MIL-I-6181D as a building block augumented with requirements tailored to the electromagnetic environment of the orbiter. Electrical bonding, grounding, wiring separation and a preliminary EMC Control Plan will be prepared
- Frequency Management - A study of the C, S, L, UHF and Ku-band rf transmitters and receivers will minimize the EMC constraints between these equipments by considering harmonics, intermodulation products and spurious responses
- Lightning Protection - This effort will satisfy the safety requirements of MIL-B-5087. It will include testing an orbiter model and selected vulnerable structural assemblies, such as, cockpit, fuel caps, joint assemblies
- Multiplexing - The necessary requirements to prevent excessive channel cross coupling between dedicated and all other wiring will be developed

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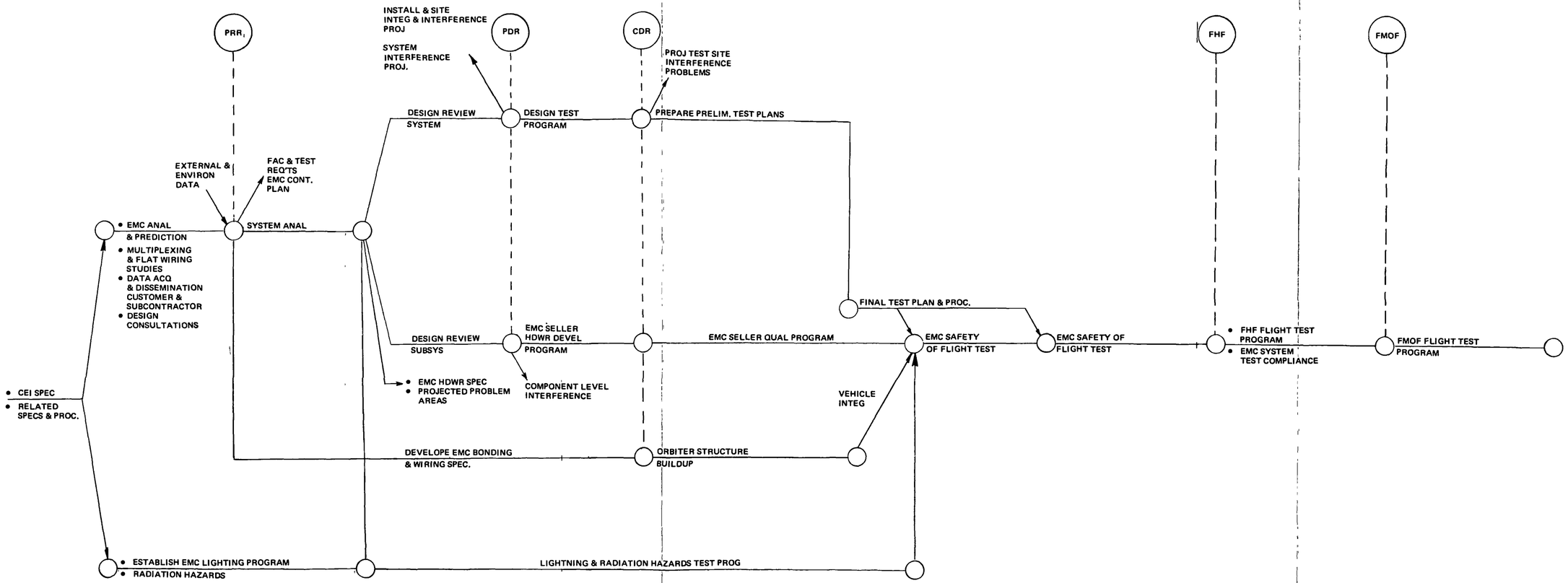

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Fig. 2.18-1 Electromagnetic Compatability Logic Network

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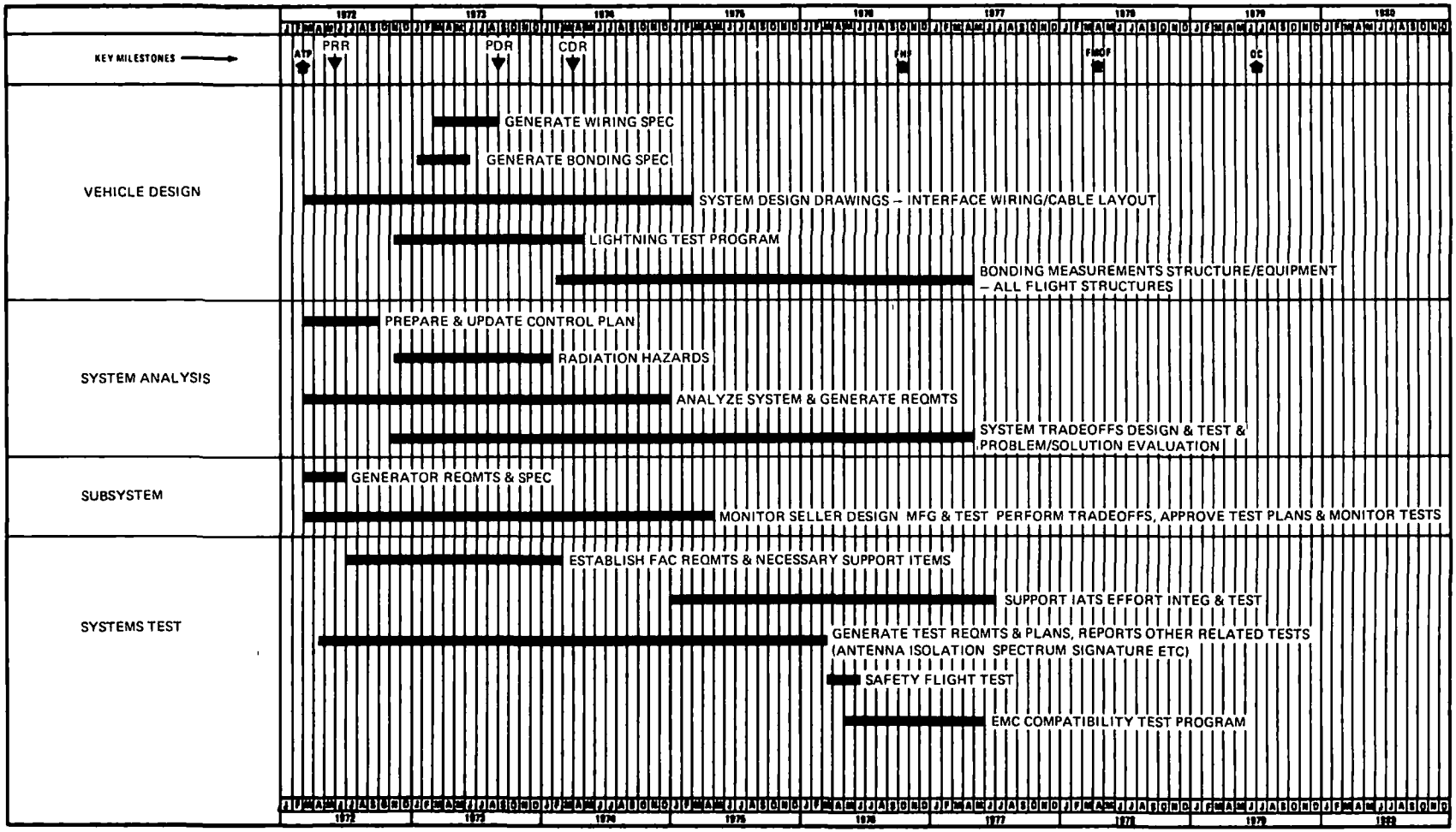


Fig. 2.18-2 Electromagnetic Compatibility (EMC)

- o Grounding - Multipoint grounds must be prevented from compromising single point grounds at "common" interfaces. The vehicle contraints as well as the costs and personnel needed to assure proper grounding of electrical circuits and shields will be investigated

2.18.2 ANALYTICAL TECHNIQUES

System analyses have helped to identify the uniuqe problem areas discussed in paragraph 2.18.1. Further analyses will be to tailor the EMC requirements to the orbiter's electromagnetic profile taking into account its missions, equipment operation profile and rf frequency allocations.

One particular analysis establishes mathematical models of each transmitter, receiver, antenna and transmission line parameters as configured on the orbiter. These models can be used, in conjunction with an established computer program, to define the EMC design constraints, frequency assignments and test frequencies. Modeling and computer analysis has been successfully used and validated for over seven years on other Grumman programs such as: E-2C, LM, EA-6B and F-14A.

2.18.3 TEST FACILITIES

Preliminary analyses indicates that a controlled test environment will be essential in demonstrating the EMC of the orbiter. The degree of controlled environment is govered by many factors:

- Sensitivity of the rf receivers
- Power output of the transmitters
- RF reflection surfaces in the test area
- Noise introduced by the factory checkout equipments
- Ambient noise level at the test site

- Weather conditions for outside testing
- Federal Communication Commission, Military, NASA and range safety rules and regulations restricting operation of the orbiters, and supporting test equipment, rf transmitters. (These restrictions will be more severe five years hence)

A shielded anechoic hangar would provide the optimum controlled environment and reduce test time to the minimum, including flight test. However, alternate methods for demonstrating compatibility may not require such a hangar. Cost effectiveness of alternate methods will be examined to assure that the EMC test objectives are not compromised by producing inconclusive or non representative results.

2.19 FLIGHT CONTROL SYSTEM INTEGRATION

The basic objective of the flight control system (FCS) integration section is to establish overall flight control requirements and system design approach. The integration function is performed at the system level because of the interdisciplinary nature of the involved subsystems. The integration function also provides the focal point for coordination of all FCS related activities performed in the following subsections:

2.1 Reliability

2.5 Certification requirements

2.6 Checkout requirements and criteria

2.8 Aerodynamics

2.13 Trajectories

2.14 Simulation

3.6 Flight control mechanical equipment

4.0 Propulsion - ACPS/ABE/MAIN/OME

5.1 GN&C avionics

5.2 Data management

5.5 Displays and controls

10.6 Integrated systems test and simulation

The FCS integration section will establish the system level design guidelines to which all of the above sections will respond. Design continuity among the various analysis, hardware, simulation and test sections will be the responsibility of the FCS integration section.

The major FCS integration activities are directed at establishing a system design which includes:

- FCS launch monitor functions
- Main engine thrust vector control
- Normal and abort separation control
- On-orbit control
- Docking/stationkeeping control
- Entry aero/ACPS control
- Aerodynamic cruise control
- Approach and landing control
- Ferry operation/horizontal takeoff control

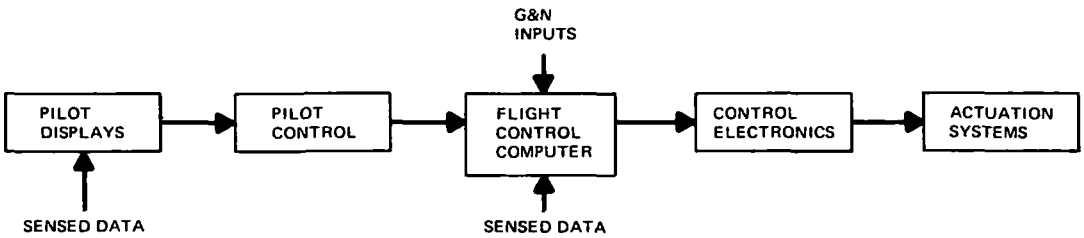
For each of these control functions, related modes (auto, manual, guidance coupled) are identified along with all elements (hardware/software) required to implement each mode. Dynamic characteristics, failure effects and failure detection logic requirements are determined for each element. All modes are represented by a series of system level schematics.

Each control mode is defined to the next level of detail in terms of math models of system elements, definition of control equations, control and mode failure detection schemes. System performance and key parameters are established and verified through detailed analyses and simulation. Emphasis is concentrated on mode performance, computer solution rates, interface update rates, quantization/accuracy, element and mode failure detection, off nominal design parameter sensitivities.

Hardware/software interface compatibility among the affected FCS subsystems (displays and controls, GN&C avionics, propulsion, etc.) is a prime responsibility of the FCS integration section. As flight control hardware elements and flight software are developed, they are phased into three dynamic verification facilities.

- Flight control hydraulics test laboratory
- Integrated avionics test laboratory
- Full mission simulation laboratory

These integration facilities are described in subsection 10.6, Integrated System Test and Simulation.



PILOT CONTROLS	COMPUTATIONAL FUNCTIONS	ACTUATION SYSTEMS
• MISSION PHASE PANEL • AUTOPILOT CONTROL PANEL • 3 AXIS ACPS ROTATION • 3 AXIS ACPS TRANSLATION • MAIN ENGINE THROTTLE • OMS START/STOP • GANGED ABES THROTTLE • INDIVIDUAL ABES THROTTLE • PEDAL RUDDER CONTROL • PITCH & ROLL SIDE ARM • PEDAL STEERING/BRAKING • SPEED BRAKE CONTROL • MANUAL TRIM SENSED DATA • 3 AXIS REF ATTITUDE • 3 AXIS BODY RATE • 3 AXIS BODY ACCEL • STATIC PRESSURE • TOTAL PRESSURE • TOTAL TEMPERATURE • ANGLE OF ATTACK • SIDE SLIP DISPLAY DATA • 3 AXIS REF ATTITUDE • 3 AXIS REF ATT RATE • DOCKING DISPLACEMENTS • ENTRY CONTROL DISPLAY • NORMAL LOAD FACTOR • LATERAL LOAD FACTOR • INSTRUMENT LANDING DATA	• LAUNCH INITIALIZATION • LAUNCH MONITORING • ABORT SEQUENCE • HIGH q ABORT BLENDING • MANUAL TRANSLATION • TVC (NORMAL & ENGINE OUT) • 3 AXIS SPACE DAP – RATE CMD ATT HOLD (INERTIAL & LV REF) – MINIMUM IMPULSE – ACCELERATION – HI/LO ACPS THRUST – ROTATION PRIORITY OVER ΔV – INDIVIDUAL THRUSTERS – SLOSH FILTER • ENTRY DAP – PITCH TRIM – YAW TRIM – COORDINATED BANK – GUIDANCE STEERING – AERO/ACPS BLENDING • AERO DAP – ROLL RATE CMD ATT HOLD – PITCH RATE/ACCEL ATT HOLD – AUTO TURN COORDINATION – BENDING FILTER – SIDESLIP OVERRIDE – RUDDER/SPEED BRAKE LOGIC • GUIDANCE COUPLING – INSERTION ORBIT & ENTRY STEERING – AUTO THROTTLE – HDG/GND TRK HOLD – ALTITUDE HOLD – AIRSPEED HOLD – AUTO SPEED BRAKE – AUTO LANDING • FAILURE DETECTION/ ISOLATION	• MAIN ENGINE TVC SINGLE DUAL TANDEM PWR ACTUATOR & 2 INDIVIDUAL SECONDARY ACTUATORS PER AXIS • ELEVONS 2 DUAL TANDEM PWR ACTUATORS PER SURFACE CONTROLLED BY 4 SECONDARY ACTUATORS • RUDDER SPLIT SURFACES FOR SLIDESLIP CONTROL & SPEED BRAKE INDIVIDUAL DUAL TANDEM ACTUATOR POWERS EACH OF 4 SURFACE TWO SECONDARY ACTUATORS PER POWER ACTUATOR • ATTITUDE CONTROL PROPULSION SYSTEM

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Fig. 2.19-1 Flight Control System Functions

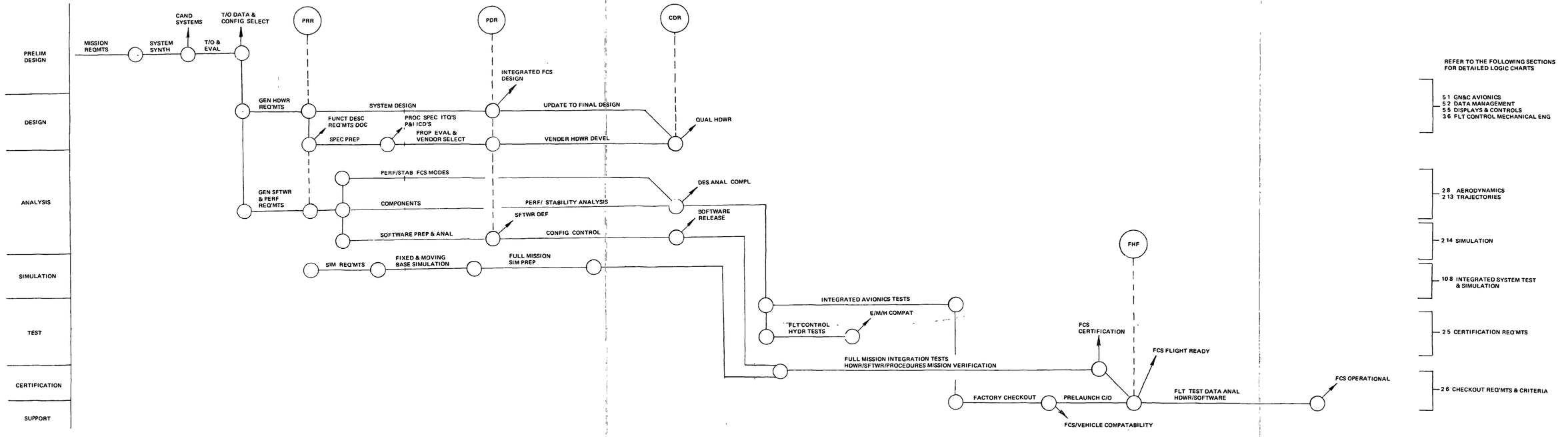

Fig. 2.19-2 Flight Control System Integration Logic

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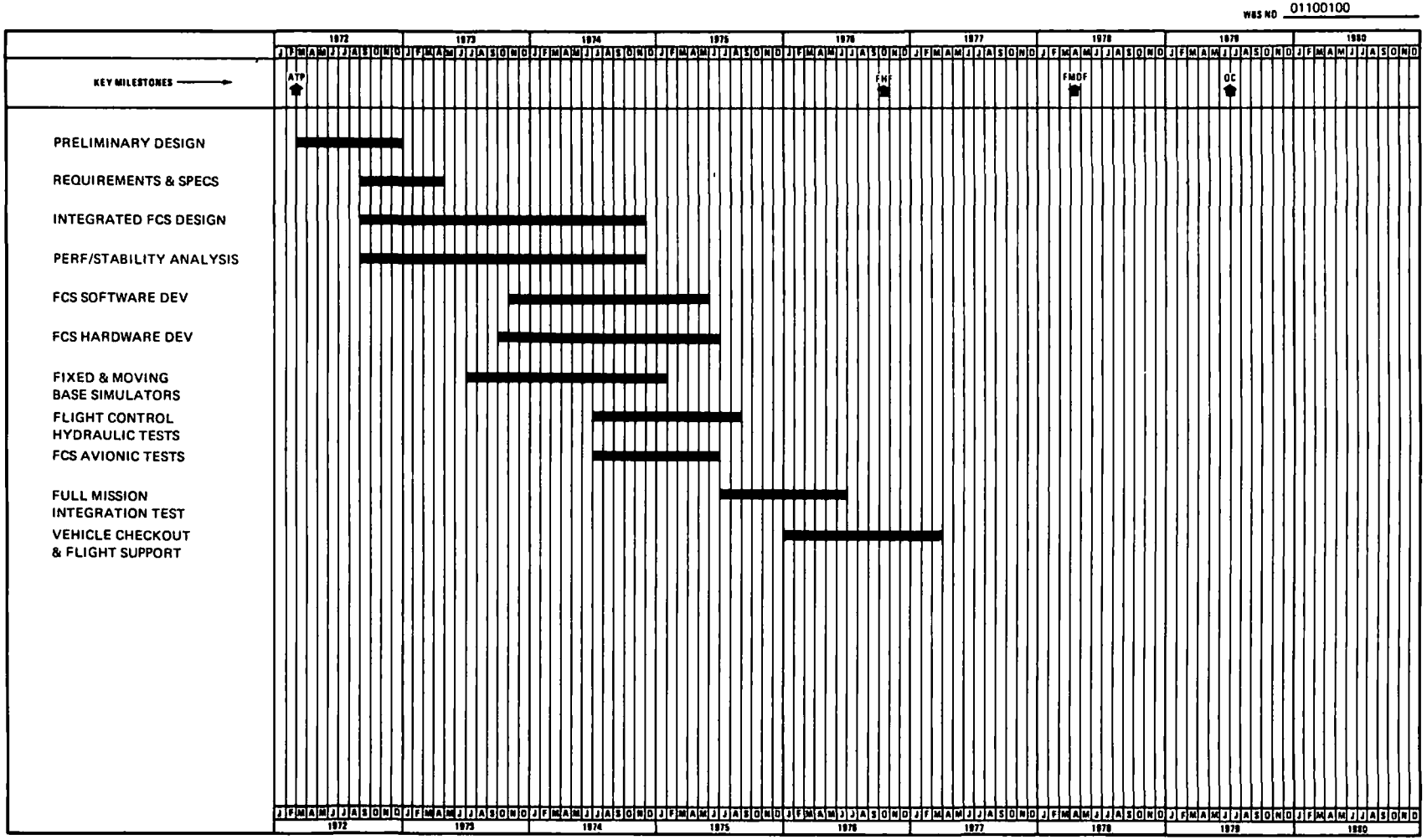

Fig. 2.19-3 Flight Control System Integration Schedule

2.20 ORBITER WIND TUNNEL TEST PLAN

2.20.1 INTRODUCTION

The orbiter wind tunnel program is an integrated test plan which provides an experimental data base for analysis and tradeoff studies, simulation, design and verification at a reasonable cost and risk to meet major milestones and reviews. A sequence diagram of the wind tunnel program and the data output is shown in Fig. 2.20-1.

The program scope will range from ascent performance with external tanks, through tank separation, reentry, terminal flyback and ferry. The disciplines of aerodynamics, thermodynamics and loads and dynamics will drive the major portion of their experimental data base from this program. The total wind tunnel plan for the orbiter, booster and the launch configuration is shown in Fig. 2.20-2. Orbiter testing includes 111 tests for a total of 28,000 hours using 42 models. A detailed breakdown of test hours by agency and facility against time and speed range and disciplines are shown in Tables 2.20-1 and 2.20-2.

2.20.2 AERODYNAMICS

The aerodynamic portion of the test program represents 59% or 16,640 hours of orbiter testing. The test program will develop an experimental data base for stability, control, damping, trim and drag of the orbiter. These characteristics are both static and dynamic in nature and will include the external tanks when appropriate. Abort separation data of the tanks and abort flight mode characteristics of the orbiter with tanks will also be obtained over a wide speed range. In addition, special tests such as orbiter spin sensitivity, recovery, and prevention; ABES location, installation penalties and deployment effects; and ACPS external flow field interaction effects on control effectness will be investigated; and sonic boom pressure signatures will be obtained.

Fifteen aerodynamic models will be required. The static aerodynamic models are basically all metal or metal core with wood or similar workable material for contours. The dynamic stability models are usually light weight thin shell models. The particular method of construction is defined by the tunnel loads, use, and extent of ad hoc revisions expected.

Six component force and moment measurements will be made whenever possible for both the orbiter and orbiter with tanks. For separation data, forces and moments of the orbiter and tanks will be measured individually. Both matrix coverage as well as captured trajectories are planned.

In addition, buffet onset measurements will be made using measurements and techniques such as wing root bending strain gages, trailing edge pressures, tip accelerometers, etc. Flow visualization in the forms of schlieren, shadowgraphs, oil flows, smoke, tufts and vapor will be used to verify good flow in the tunnels, shock wave location, separated regions, vortex location and other aerodynamic phenomena. Where required and available, state-of-the-art techniques such as laser and halographic schlierens and electron beam will also be utilized to their maximum.

2.20.3 AERO-THERMODYNAMICS

The thermodynamic portion of the test program represents 20% or 5420 hours of orbiter testing. The test program will provide an experimental base for the overall heating environment of the orbiter. This will include the interference heating experienced by the orbiter and the tanks during ascent, abort flight modes and reentry heating. Special problems such as base heating during reentry, base heating and pressure with main engines on, ACPS and canopy heating will be investigated and defined.

Eighteen orbiter models will be required. The models will be of three basic types: paint models made of low conductivity materials for phase change paint testing; thin skin thermocouple models; and conventional construction models with inlayed thin film heat flux gages. Wherever required and possible special models, such as a hypersonic pressure model, or additional instrumentation will be made to fit the need. Schlieren, shadowgraph and oil flows will be used for flow field and surface flow visualization. Where possible, state-of-the-art visualization techniques will be used.

2.20.4 LOADS AND DYNAMICS

The loads and dynamics portion of the test program represent 21% or 5940 hours of orbiter testing. The test program will develop an experimental data base for the overall aerodynamic loads, both static and dynamic, of the orbiter and the orbiter plus the external hydrogen tanks. The program will also aid in establishing the aeroelastic effects that need

be applied to the rigid body characteristics determined in the aerodynamic portion of the program. Special tests such as determination of aerodynamic noise and the use of dynamically scaled external tanks to determine the single-degree-of-freedom flutter of the tank will be conducted.

A total of nine orbiter models will be required. Static load measurements will be made using rigid models. Six components force balances will be used wherever possible for orbiter and external hydrogen tank measurements. Special strain gage circuits will be designed and build for component loads such as wing or tail bending moments, engine nacelle loads, and hinge moments.

Pressure models will be made of the orbiter and tanks. These models will be capable of steady state as well as dynamic and acoustic pressure measurements.

Dynamic loads measurements will be made using plate, and dynamically scaled component and full three dimensional models. Special strain gage circuits will be designed and built to determine dynamic response, frequency and amplitude.

TABLE 2.20-1 AGENCY SCHEDULE, ORBITER CONFIGURATION (TEST HOURS)

Facility	1972 1	2	3	4	1973 1	2	3	4	1974 1	2	3	4	1975 1	2	3	4	1976 1	2	3	4	1977 1	2	3	4	Total
NASA																									
Ames				845	450	120	320	200	240	450		1940	200	240	880	250	200	1120		570	400	480		930	9,835
Langley		540	80	560	240		720	240	480		200	480		480	400	240	480		480			720		480	6,820
Contractor		700	200	1120	300	640	440	640	100	480	200		100	200		100	320			320		80	80		6,020
Air Force			80		200	320	240					200	640	240						200	560				2,680
Private			160	160	380	240	420	400			500		300												2,560
																									27,915

TABLE 2.20-2 FACILITY SCHEDULE, ORBITER CONFIGURATION (TEST HOURS)

Facility	1972 1	2	3	4	1973 1	2	3	4	1974 1	2	3	4	1975 1	2	3	4	1976 1	2	3	4	1977 1	2	3	4	Total
ARC 6 x 6 ft				120		120	120		240			240						240						480	1560
ARC 11 ft												400		240				400			400				1440
ARC 3.5 ft												480			480			480				480			1920
ARC 14 ft				325	250		200			250		500			200	250				250				250	2475
ARC Unitary				200	200			200		200		200			200		200			200					1600
ARC 12 ft Press.				200								120	200							120				200	840
LRC 8 ft		240		240	240		240	240																	1200
LRC 16 ft				240			240		480			480				240	240		480			240		480	3120
LRC 4 ft Unitary							240							480											720
LRC, VDT		300	80								200														580
LRC 31 in.				80																					80
LRC Spin															400										400
LRC Unitary																	240					480			720
CAL 96 in.		160	160		180	240	420	400			300		300												2160
CAL Plume					200						200														400
AEDC 16T						320							640								320				1280
AEDC Hyp Vel		80																							80
AEDC 16S							240							240							240				720
AEDC B&C					200							200								200					600
GAC 7 x 10 ft	400			400		400	200	400	100					200		100									2200
GAC 26 in.				240			240																		480
GAC 36 in.	300	200	80		100	240		240		480			100												1740
GAC Plume					200						200						320		320			80	80		1200
GAC Shock				400																					400
																									27,915

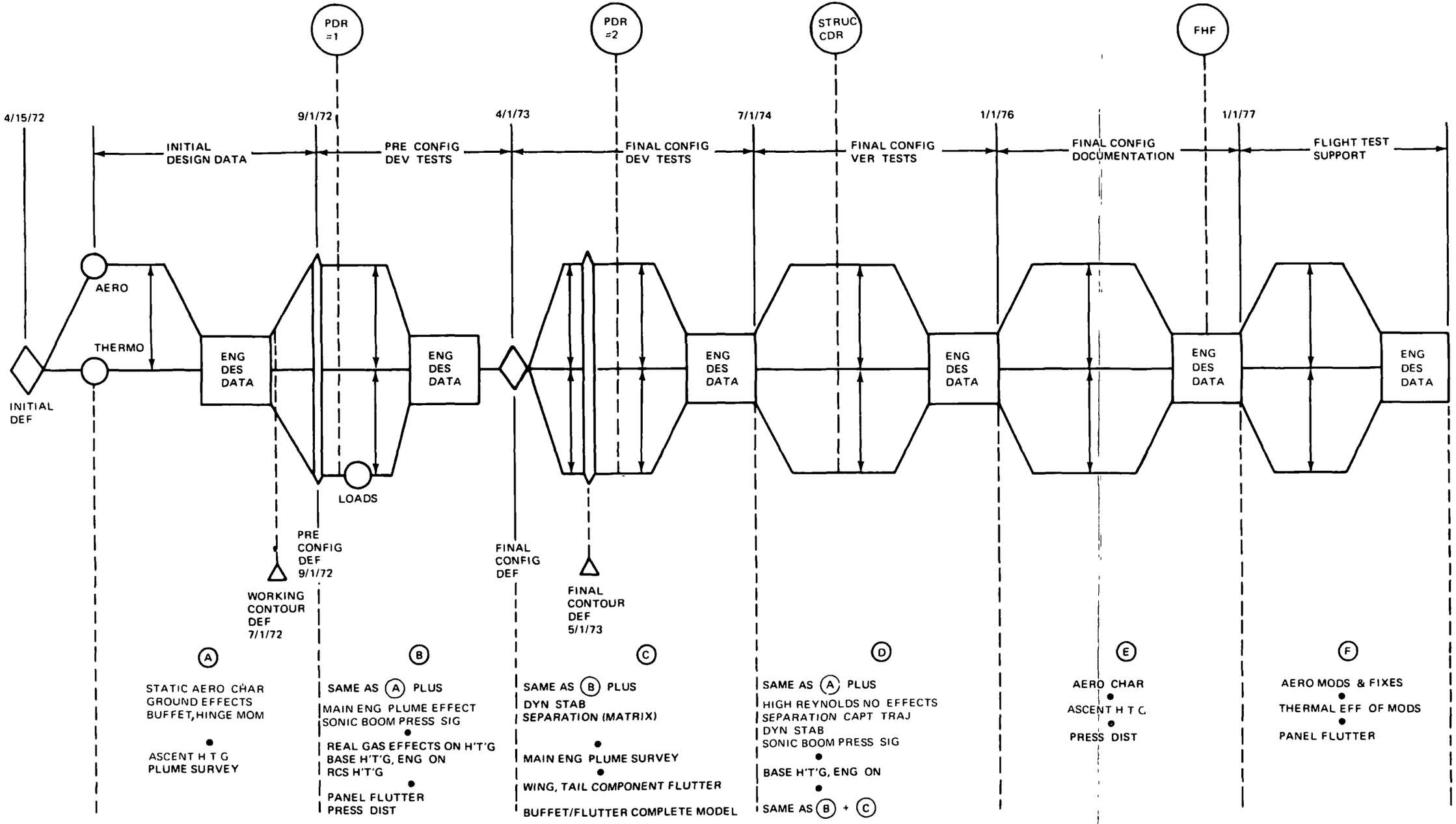

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Fig. 2.20-1 Wind Tunnel Flow Diagram

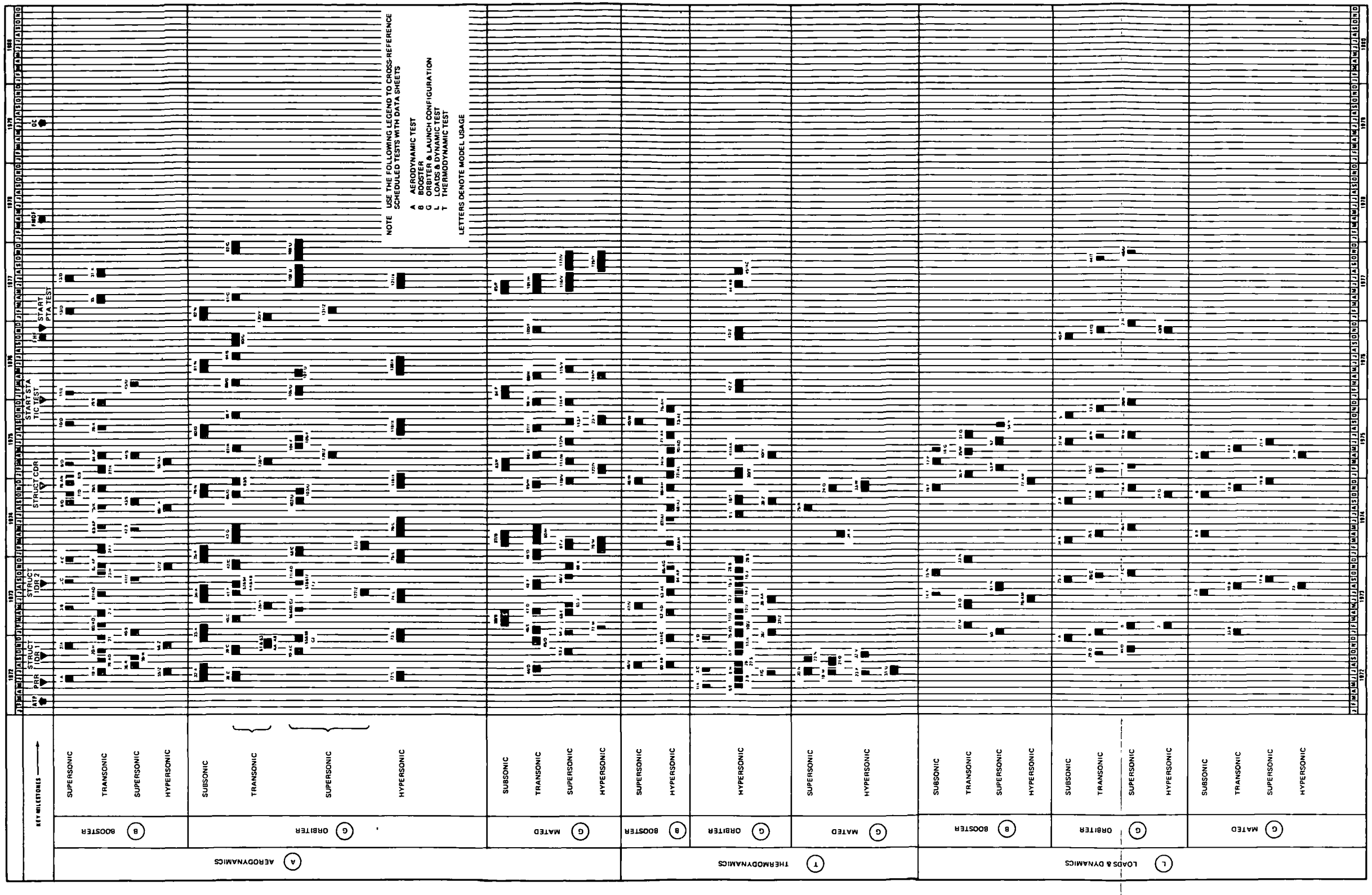

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Fig. 2.20-2 Integrated Wind Tunnel Program

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Section 3

AIRFRAME

3-1 AIRFRAME

The H-33 Orbiter airframe consists of the following major subsections;

- Aero-Surfaces (3.1)
- Fuselage (including internal tanks) (3.2)
- External Tanks (3.3)
- Thermal Protection System (3.4)
- Crew and Passenger Accommodations (3.5)
- Flight Control System (3.6)
- Recovery (Landing gear and deceleration chute) (3.7)
- Payload Deployment/Retrieval (including docking) (3.8)
- Pyrotechnic Devices (3.9)

In addition, a Contour Development and Equipment Lines function provide integration and support to these subsections.

The Orbiter airframe, Fig. 3-1 is a conventional titanium semi-monocoque design, which utilizes proven materials, existing analysis, manufacturing techniques, and test procedures. The titanium technology required for the orbiter airframe has successfully been developed on Grumman's F-14 Program. The pressure shells of all tanks and the crew cabin are fabricated from flight proven 2219 aluminum alloy, using design approaches similar to that employed on the LM and Saturn vehicles. These shells are independently supported on the airframe permitting ready removal for either inspection or replacement. A thermal protection system (TPS) protects the titanium airframe and internal components

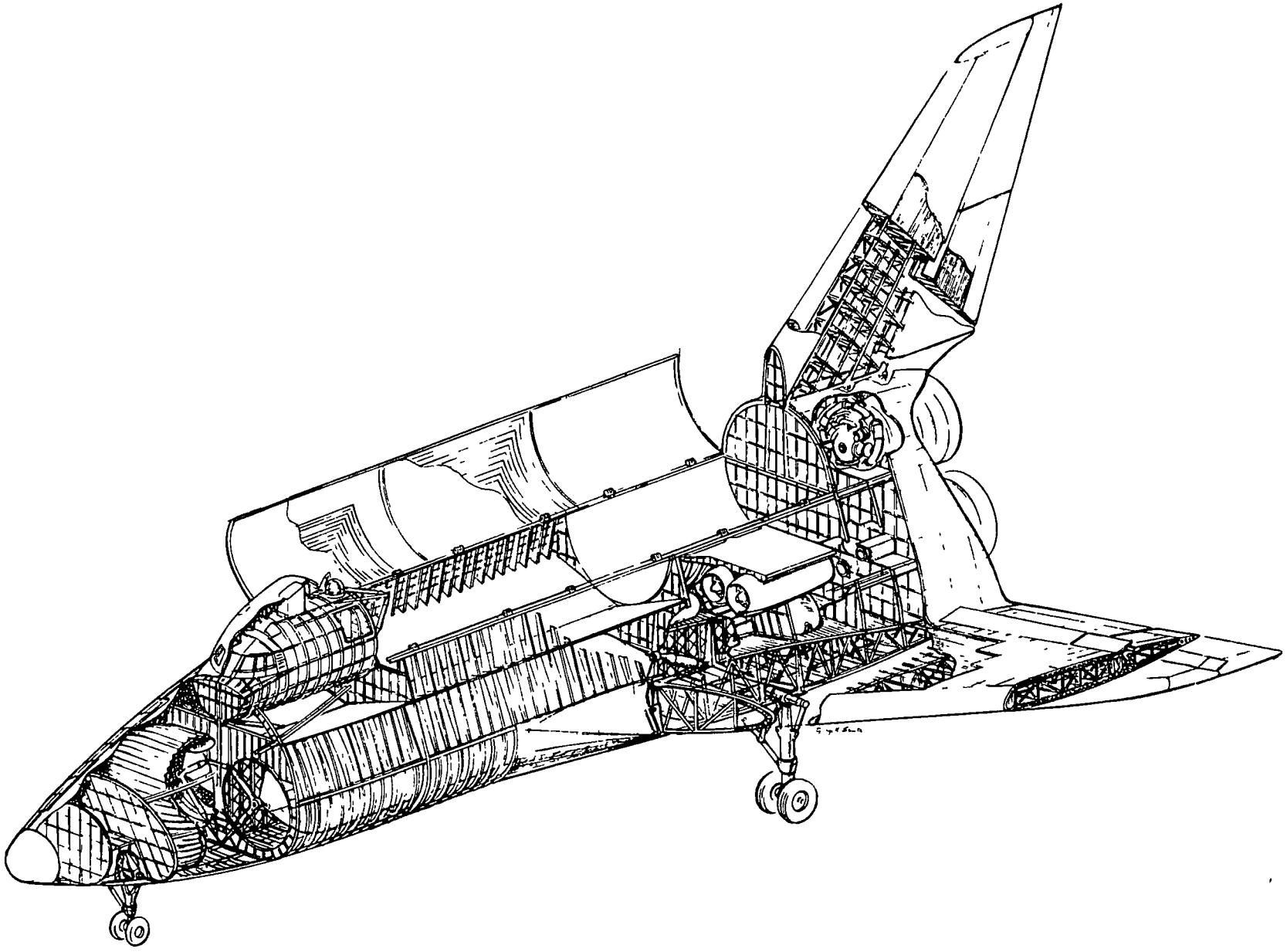

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Fig. 3-1 H-33 Orbiter Structural Arrangement

from ascent and reentry temperatures. Since the TPS forms the aerodynamic shape of the orbiter, the internal titanium airframe is configured in simple geometric shapes (i.e., no double curvature panels) thus minimizing tooling and fabrication costs.

3-1.1 STRUCTURAL SYSTEMS

Grumman Aerospace Corporation can provide a structural design team that has a continuous, integrated, uninterrupted record of performance extending over forty years. This team has an unexcelled, proven record in the design and large scale production of high performance military aircraft, commercial aircraft, and spacecraft. Their background includes design of all categories of Naval aircraft from the FF-1 (1930) to the current F-14 Army OV-1 Series, foremost commercial business aircraft currently in operation and production (G-I and G-H Gulfstreams), highly sophisticated spacecraft such as the Orbiting Astronomical Observatory and Lunar Module of the Apollo program.

To achieve the advancement in performance requirements in each subsequent program, Grumman's design team, in conjunction with the research and advance design study groups continually advanced the state-of-the-art in materials, design, fabrication, and joining and fastening techniques. Grumman has designed and is currently producing the most advanced titanium alloy structural subassemblies in production, that is:

- The F-14 wing center section box structure - an assembly of machined titanium alloy parts mechanically welded together in a vacuum chamber by the electron beam process and sealed to provide an integral fuel tank
- The F-14 wing outer panel box beam section - an assembly of titanium alloy skins, ribs and beams attached together by an advanced "interference fit" riveting process and sealed to provide an integral fuel tank. (The hot forming of the machined titanium wing skins represents distinct advancement in state-of-the-art)

Some advanced flight proven composite materials structures are:

- F-111 boron-epoxy stabilizer skin panels
- F-14 boron-epoxy stabilizer skin panels - an advancement in the optimization of fiber composite structure to provide desired aeroelastic characteristics while meeting all other structural and aerodynamic criteria

The orbital structural task is accomplished by cost effective structure defined on detail layouts supplied to drafting services and providing all necessary definition for all purchasing, manufacturing, and assembly procedures.

The structure will be sized using various basic computer programs and computer graphics to rapidly size and refine initial configurations as inputs for more sophisticated analytical programs (i. e. IDEAS, refer to subsection 2.9) to follow. Simplicity in design will be heavily stressed and maximum use will be made of state-of-the-art techniques to assure maximum structural reliability, maintainability, and quality assurance status by non-destructive evaluation methods relying heavily on direct visual inspection. Joining techniques such as electron beam welding, interference fit fastening system, use of stress wave guns in fastening, will be included where applicable. Simplicity with emphasis on mission life, replaceability, and inspection will be the keynote of TPS design.

Tanks will be designed for maximum safety, mission life, inspection and handling. The unique external tanks will be supported by statically determinate trusses. Knowledge gained from the successful Apollo program will be utilized and simplicity in design will be heavily emphasized.

3-1.2 CONTOUR DEVELOPMENT - GEOMETRIC DEFINITION AND CONTROL

Recognizing the exacting shape control mandatory in the shuttle concept, the highly sophisticated automated Master Dimensions Program (MADS), Automated and Integrated Drafting System (AIDS), Auto Model Program (AMP), Auto Template System (ATS) are used individually and/or sequentially to establish and maintain current exact configuration geometries. Skilled personnel manipulate these programs, mathematically model configurations, provide; rapid and accurate curve fits, area diagrams, slope diagrams, and integrate geometric characteristics to support numerically controlled machine tools, with immediate response capability for rapidly changing wetted areas and/or skewed cuts, etc. These programs and their implementation have significantly reduced production manhours while significantly improving parts and shape accuracy and interface control in the F-14 program. They are currently being expanded to further reduce shuttle costs.

The Orthomat drafting machines produce 30% to 50% of all contoured structural machine part drawings and 20% to 40% of all contoured sheet metal part drawings. These same machines also supply 60% of all structural diagram drawings, ground vibration survey deflection drawings, structural node idealization maps, envelope environmental characteristic drawings, isometric, perspective and exploded view illustration drawings.

The versatility and rapid response capability gives greater visibility at an earlier point in time to the stated analytical efforts and made such data reduction and presentation one of the most essential tools on the F-14 and F-111 programs.

Numerically controlled automatic milling machines are supplied with control tapes from the above programs to directly produce forming tools, bonding fixtures, interface fixtures and templates. Use of these direct tapes is especially valuable in such an extremely large vehicle as the shuttle and will eliminate many costly hard contour mockups in the tooling effort. This single data source provides the most accurate contour reproduction possible, which was not achievable under the older mockup methods.

The MADS system efficiently reduces effort by substituting implied programming for direct programming combined with standard commands (feed-rate, speeds, etc.)

3-1.3 EQUIPMENT LINES - INSTALLATION AND CONTROL

This group determines wiring and/or piping volumetric requirements and allocation, compatibility or separation requirements (EMI), interfaces, and most efficient routing of all electrical, hydraulic, pneumatic, and coolant lines in the vehicle. For the orbiter, this will be extremely vital and cost effective as realized on the F-14, OAO and all LM's.

The Computer Aided Design of Equipment Lines Tubing (CADET) computer program is available for the accurate design layout of actual lines.

A full scale mockup of the vehicle with complete line and harness installations is used as a run verification and preliminary manufacturing tool in the design stage. This is fully discussed in subsection 10.1.3 "Structures, Lines Run and Equipment Integration Mockup."

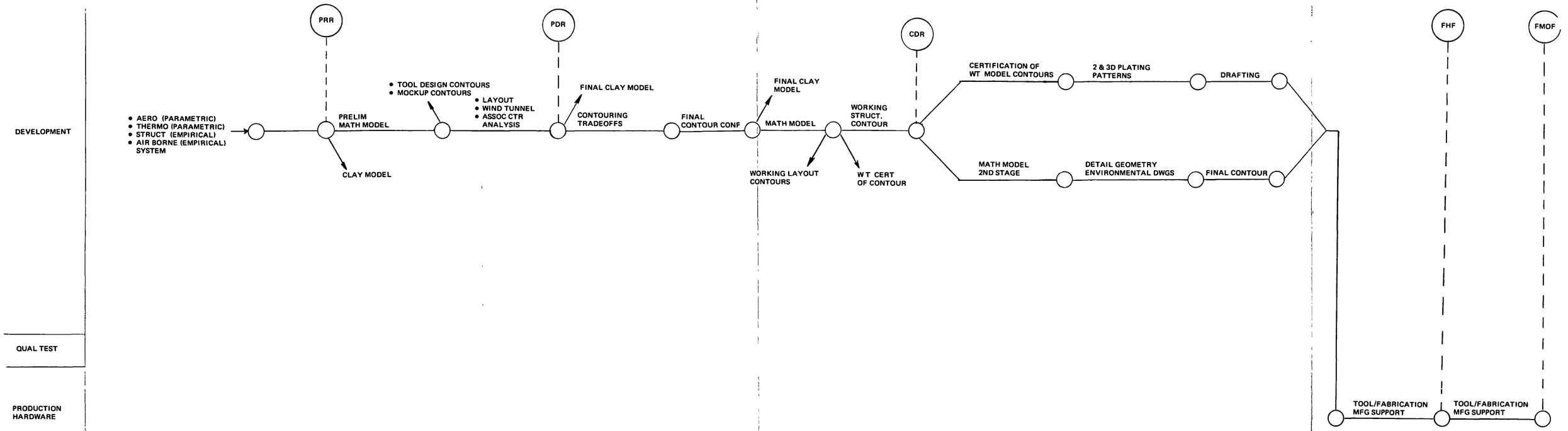

Fig. 3-2 Airframe Contour Development Logic

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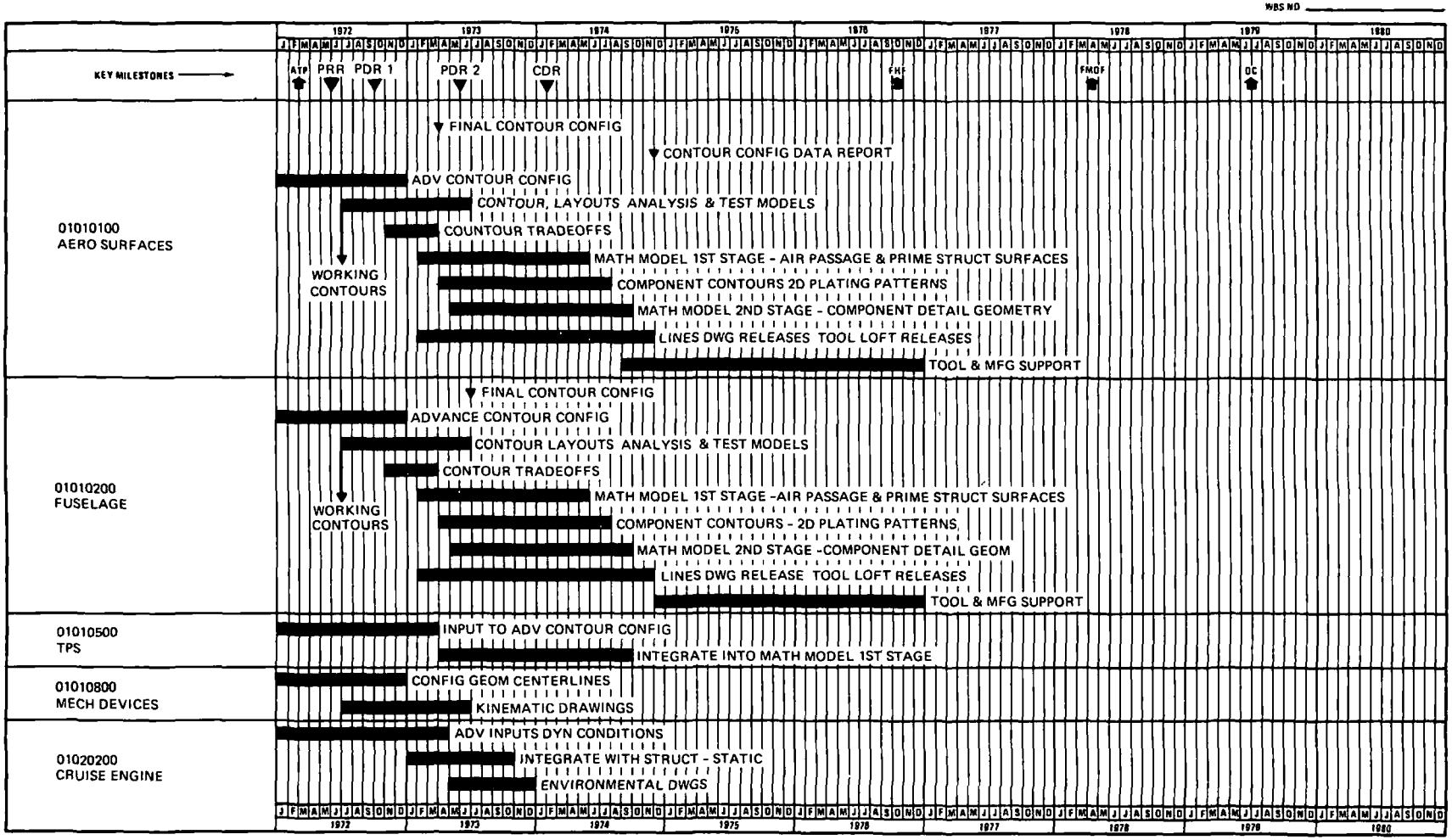

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Fig. 3-3 Airframe Contour Development Schedule (Sheet 1 of 2)

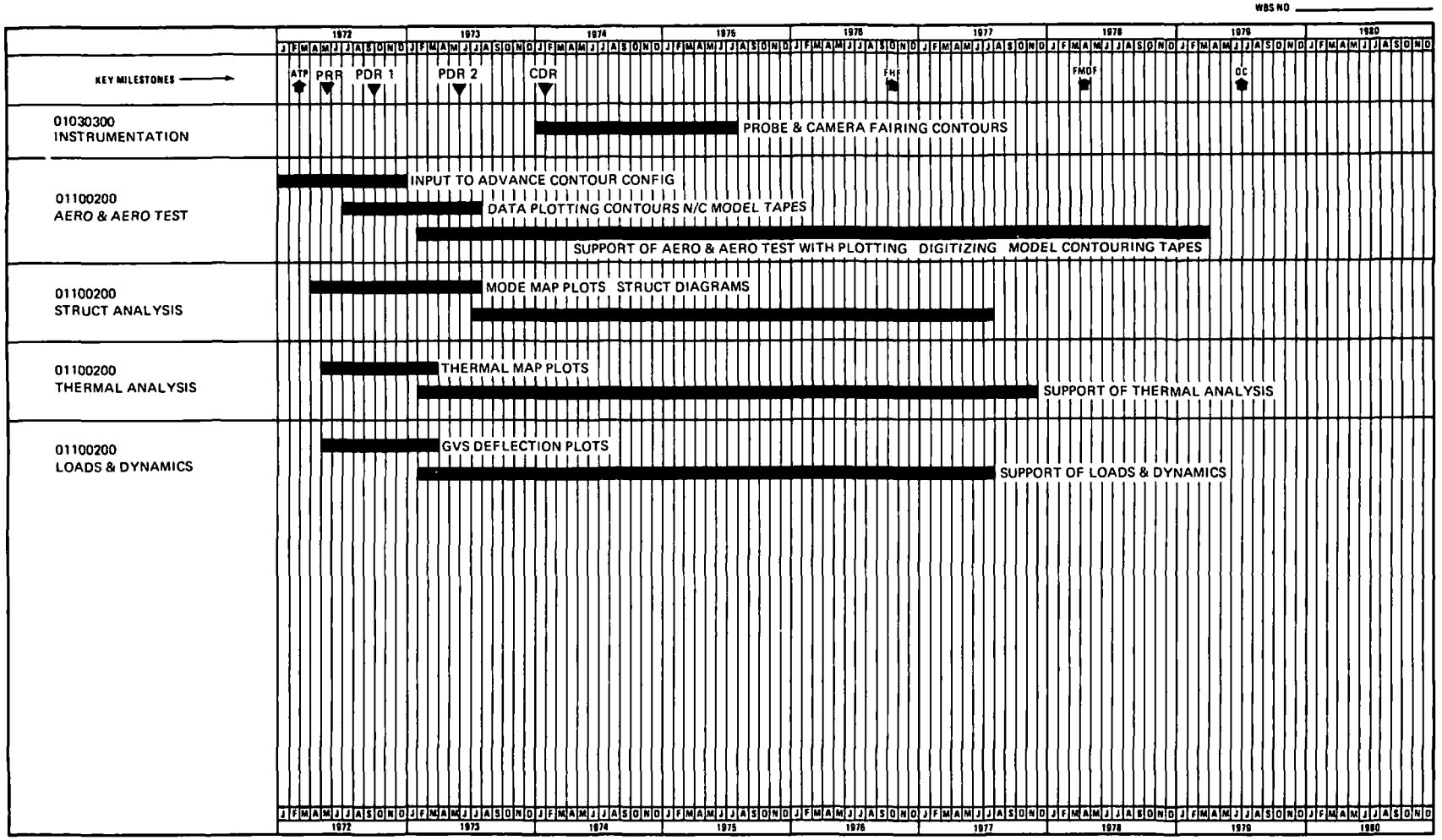

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Fig. 3-3 Airframe Contour Development Schedule (Sheet 2 of 2)

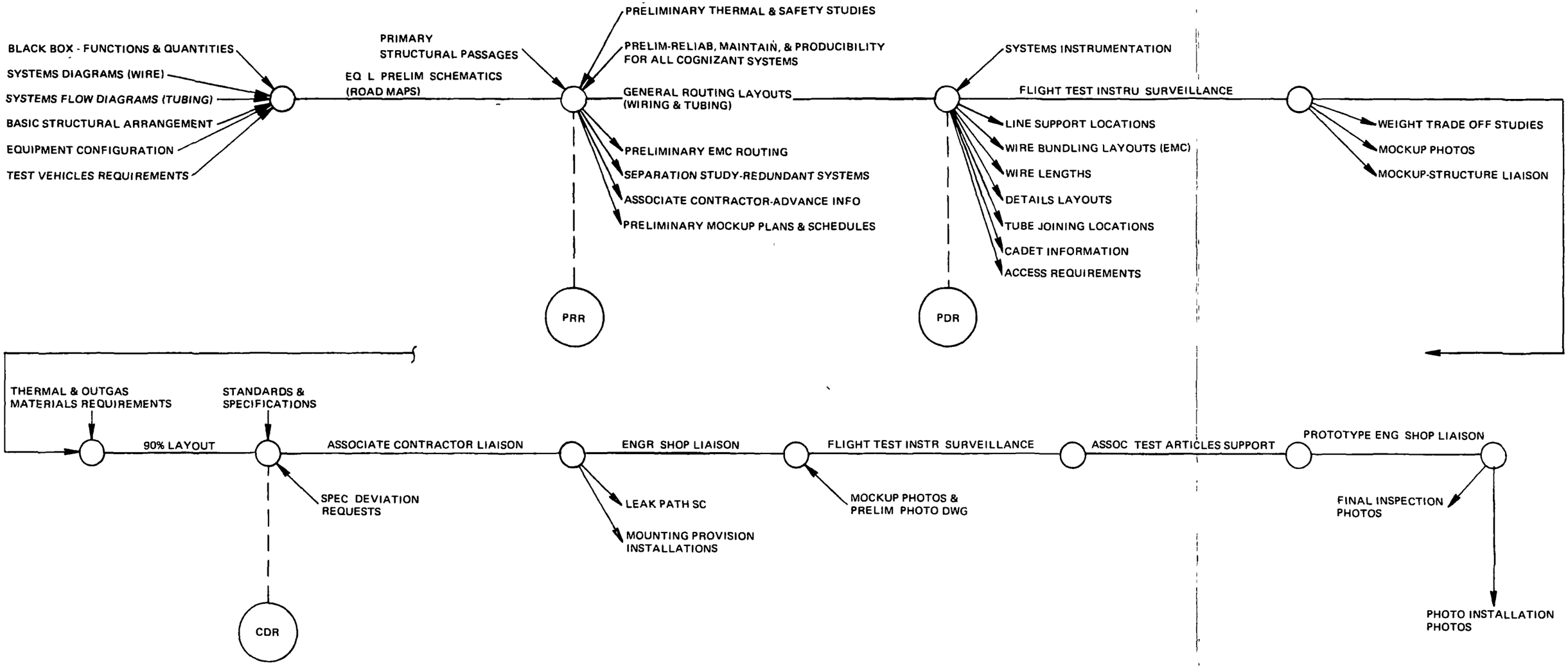

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Fig. 3-4 Airframe - Equipment Lines Logic Network

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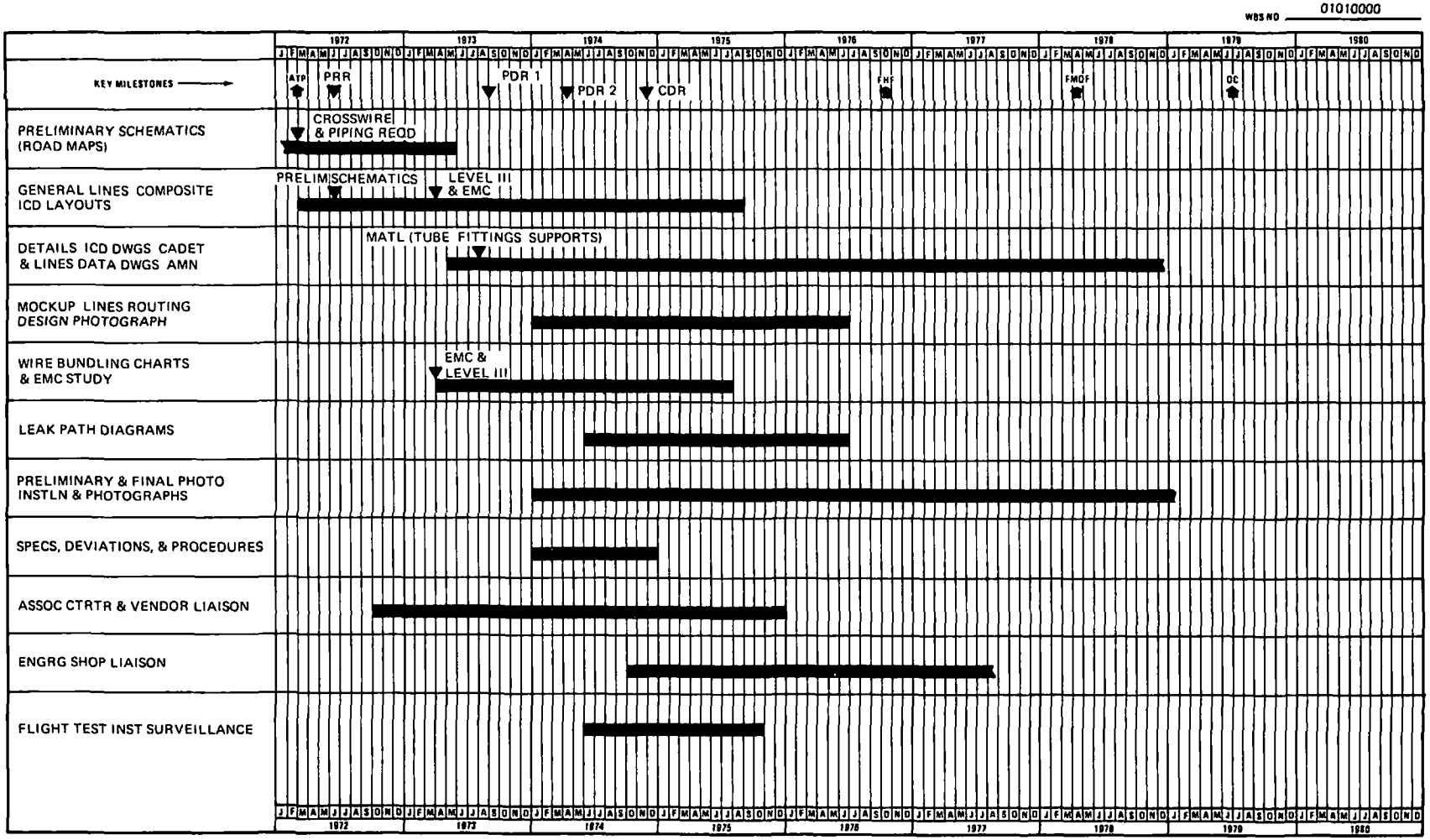

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Fig. 3-5 Airframe Equip Lines Schedule

3-1.4 CREW STATION - EQUIPMENT AND PASSENGER ACCOMMODATIONS

This subsystem addresses itself to one of the most important areas of any design - the man/machine integration and arrangement of working environment. To successfully achieve the sophisticated orbiter objectives, the expertise of the crew and equipment group is effectively used. Among many accomplishments can be listed the first truly integrated crew station of the past decade for the Navy, the A-6A Intruder; the E-2C operating station and the advanced F-14. The Gulfstream program, with a multitude of customer passenger-accommodation arrangements, further displays the broad scope of successfully applied commercial regulatory knowledge used to assure maximum functional benefit comfort and mission success.

This capability results from effective coordination of systems and subsystems through the marriage of the Crew Systems (Human Factors) and Crew Station design engineers. This extremely close working relationship coupled with consulting pilots and astronauts has been credibly displayed in the LM cabin design. Unique visibility, geometry, and display and control arrangements were effectively traded through, on the spot, with simulated studies, using soft mock-ups and suited experienced subjects. Similarly, the equipment arrangements and installations were resolved and effectively incorporated in the LM cabin while integrating sleeping and restraint devices, stowage provisions, and life support replenishment needs into the total environment.

Since every mission's success is predicated on operator ease in performance of tasks accomplished, optimum design to the particular environment is essential. This experienced design leadership successfully applied to every manned vehicle, space, submersible, tracked air cushion, military or commercial aircraft, etc., over the past 20 years is currently generating the maximum efficiency design for the orbiter.

3-1.5 MECHANICAL SYSTEMS

Mechanical systems airframe tasks encompass the conceptual and detail design of the following:

- Crew and passenger accommodations (seats, restraints, escape systems) (3.5)
- Flight controls (3.6)
- Landing gear (3.7)

- Mechanisms (separation, docking, engine deployment, payload deployment and retrieval) (3.8)
- Pyrotechnics (3.9)
- Fluid power (hydraulic, pneumatic) (6.3)

The personnel assigned to these tasks bring to the shuttle program exceptional expertise in aircraft and spacecraft design from their association with past and current programs, such as the F-14, EA-6B, Gulfstream, LM, OAO. The design excellence of these personnel can be judged by the following outstanding accomplishments:

- Performance of LM landing gear, including the pyrotechnic devices for deployment, structural integrity, and attenuation characteristics
- Performance of the F-14 Escape System, including the complex pyrotechnic sequencing for canopy deployment and seat catapult and rocket ignition. This system ejects two men within one second
- Performance of the OAO sunshade actuator
- Performance of the LM RCS during all flights to date
- Performance of fully powered flight control systems on current service aircraft, including one fly-by-wire system on the A-6 series of aircraft

Staff specialists in lubrication, bearings, power transmissions, wheels and brakes, and fluid power are outstanding in their fields and serve as committee members of many technical societies, contributing extensively in generating specifications to control and improve product quality and improve the state-of-the-art. Contributions from these specialists include computer programs for design optimization as exemplified by the F-14 wing pivot bearing design.

Cost-effective and reliable design is of prime importance. To this extent proven techniques will be used to the utmost on the orbiter. This philosophy does not exclude the use of new techniques as may be required by specific orbiter requirements but only after extensive advanced development work which is always progressing under the guidance of staff specialists and closely supported by our laboratory facilities.

3-1.6 COMPUTER SUPPORT REQUIREMENTS

- No known programs to rent or buy
- Purchase or rent of: two IBM 2250 Computer Graphics consoles for sole use of Structural Design in developing the aero-surfaces, fuselage, and tanks
- Develop simple programs and routines for Structural Design Computer Graphics usage

TABLE 3-1 EQUIPMENT LINES-BOOSTER/ORBITER
COMMONALITY CANDIDATES LIST HARDWARE

ITEM	COMMON	POTENTIAL COMMON	NOT COMMON	REMARKS
Fluid Joints, Coupling & Connectors		X		
Line Support Blocks		X		

TABLE 3-2 AIRFRAME FACILITY REQUIREMENTS LIST

TITLE AND DESCRIPTION	NEW
Hardware and Equipment	
6 Friden Sq. Rt. Calculators	X
10 Polaroid cameras	X
4 Manual digitizers	X
2 Editors (CRT & Processor)	X
1 Mag Tape addition to #1 Orthomat	X
1 Digitizer addition to #1 Orthomat	X
1 Orthomat	X

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3.1 AERO SURFACES

3.1.1 FUNCTIONAL DESCRIPTION

The present baseline orbiter aero surfaces structural configuration is as shown in Fig. 3.1-1 and 3.1-2. It consists of the following major groups: wing, elevons, vertical fin and rudder.

The wing provides lift during hypersonic reentry and subsonic flight. The elevon provides hypersonic and subsonic pitch control when used symmetrically and roll control when used differentially. The vertical fin and rudder provide directional stability. The rudder also provides directional control and is utilized as a speed brake.

3.1.2 PRINCIPAL FEATURES AND DESIGN CHARACTERISTICS

The wing is a five beam, multi-rib arrangement with beams and ribs of truss construction and corrugated covers top and bottom. Four wing beams carry through the fuselage and support the main landing gear. Two through torque cells, one between the first and second beams and the other between the third and fourth beams, supply excellent torsional rigidity. The lower wing cover is also the closure web of the lower fuselage torque cell.

The sophisticated F-14 wing currently in production amply demonstrates outstanding depth and capability in the design of complicated, redundant structures on a weight optimized, cost effective basis.

A comparatively inexpensive interference fit fastener system developed for, and in full production use on the F-14, will be used to significantly reduce weight and cost penalties resulting from design fatigue requirements. Carbon/carbon TPS is used on leading edge, with various TPS panels overlaying top and bottom covers.

Elevons are conventional beam and rib arrangement with corrugated sheet metal covers overlayed with EI and metal TPS with aft portion made of carbon/carbon. Significant background depth in high temperature elevon design was acquired under a joint Grumman/Air

Force program of 1964-1967. Successful advanced fabrication of slurry coated tantulum and favorable tests results were achieved.

The vertical fin is conventional beam and rib arrangement with titanium skins, metal TPS and carbon/carbon leading edge.

The rudder is designed as a hot structure using Inconel 718 material throughout its conventional beam and rib arrangement and corrugated stiffened skins.

3.1.3 RISK IDENTIFICATION AND RESOLUTION

Key potential development risks have been identified in areas such as:

- Thermal stresses (i.e. cumulative permissible cyclic creep etc.)
- Vertical tail flutter
- Maximum mission life

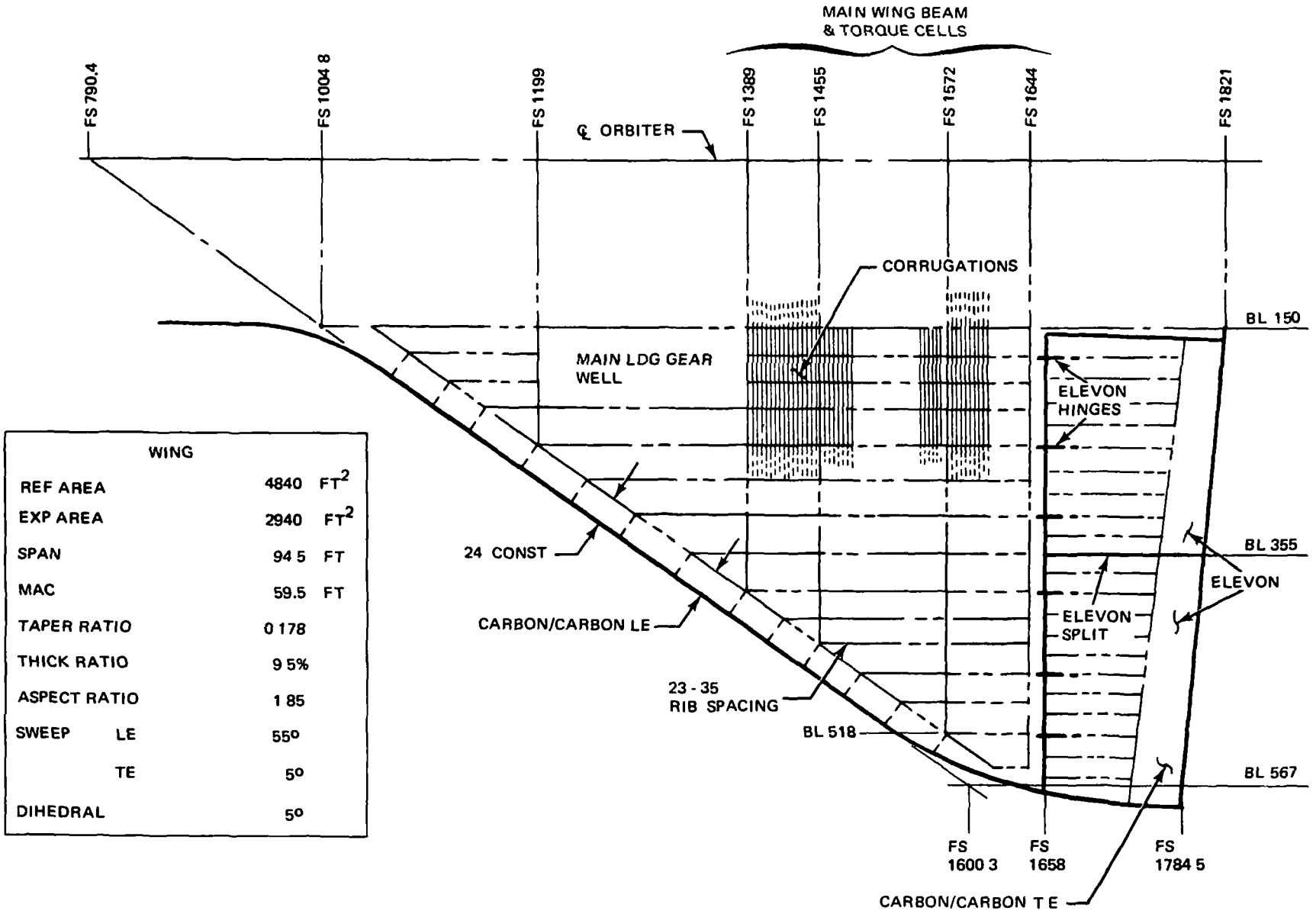
The thermal stress problem will be studied in depth, supported by appropriate detail design with particular attention to joining techniques, possible internal joint insulation, etc.

Tail flutter is minimized by a continuous closure rib support, a maximum depth two cell torque box commensurate with aerodynamic requirements, a continuous rear beam and a split rudder with redundant supports.

Maximum mission life will emphasize fail safe design previously referenced, interference fit fastening system, and optimum joining techniques. The Grumman Gulfstream II is a leading example of thorough fail safe application. Crawl through inspection access into the wing from the landing gear well provides a valuable NDE assist during turnaround intervals to continually monitor the structural integrity of the wing interior.

3.1.4 CERTIFICATION TEST PROGRAM

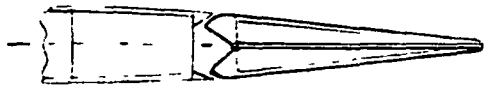
Preliminary detail structural design will stress a comprehensive series of material, element and component tests continuously conducted to generate final design guidelines and result in optimized structural configurations. Sophisticated test capability has already been significantly demonstrated in the development and qualification testing of the F-14 wing center box and pivot (EB welded titanium alloy) and boron composite faced horizontal stabilizer.



WING		
REF AREA	4840	FT^2
EXP AREA	2940	FT^2
SPAN	94 5	FT
MAC	59.5	FT
TAPER RATIO	0 178	
THICK RATIO	9 5%	
ASPECT RATIO	1 85	
SWEEP LE	55°	
TE	5°	
DIHEDRAL	5°	

Fig. 3.1-1 H-33 Wing Structural Arrangement

AIRFOIL -	NACA 0010	
AREA -	TOTAL	854 SQ FT
	RUDDER	282 SQ FT
SPAN		33 7 FT
ROOT CHORD		36.7 FT
TIP CHORD		14 FT



TYPICAL SPLIT RUDDER SEGMENT

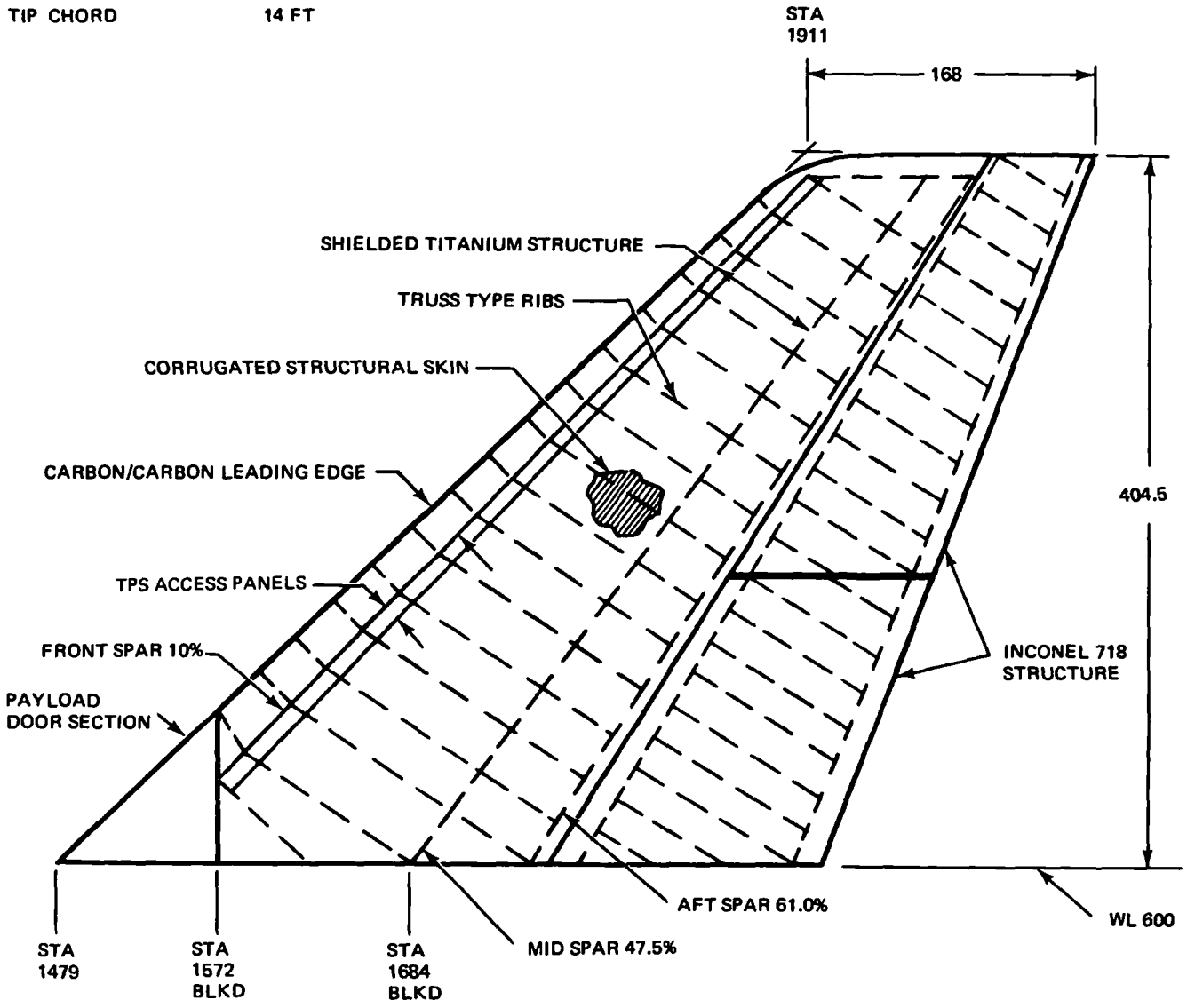


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Fig. 3.1-2 Fin Structural Arrangement

E/3.1-

Major currently scheduled DV tests are:

- Composite Materials Structural Elements - DVT to determine design allowables for various splice designs of composite materials bonded to structural alloys will be conducted on the element level early in the program to verify design assumptions
- Wing Cover Elements - Effects of flight loads with 500 to 600°F resultant heating under the TPS on corrugated wing panel elements will be verified by test
- Wing Fail Safe Elements - Tests to verify fail safe load paths will be performed using simulated percentage failures on both the element and component levels. Extensive experience on the proven Gulfstream II in this area will expedite and contribute significantly to accomplish this

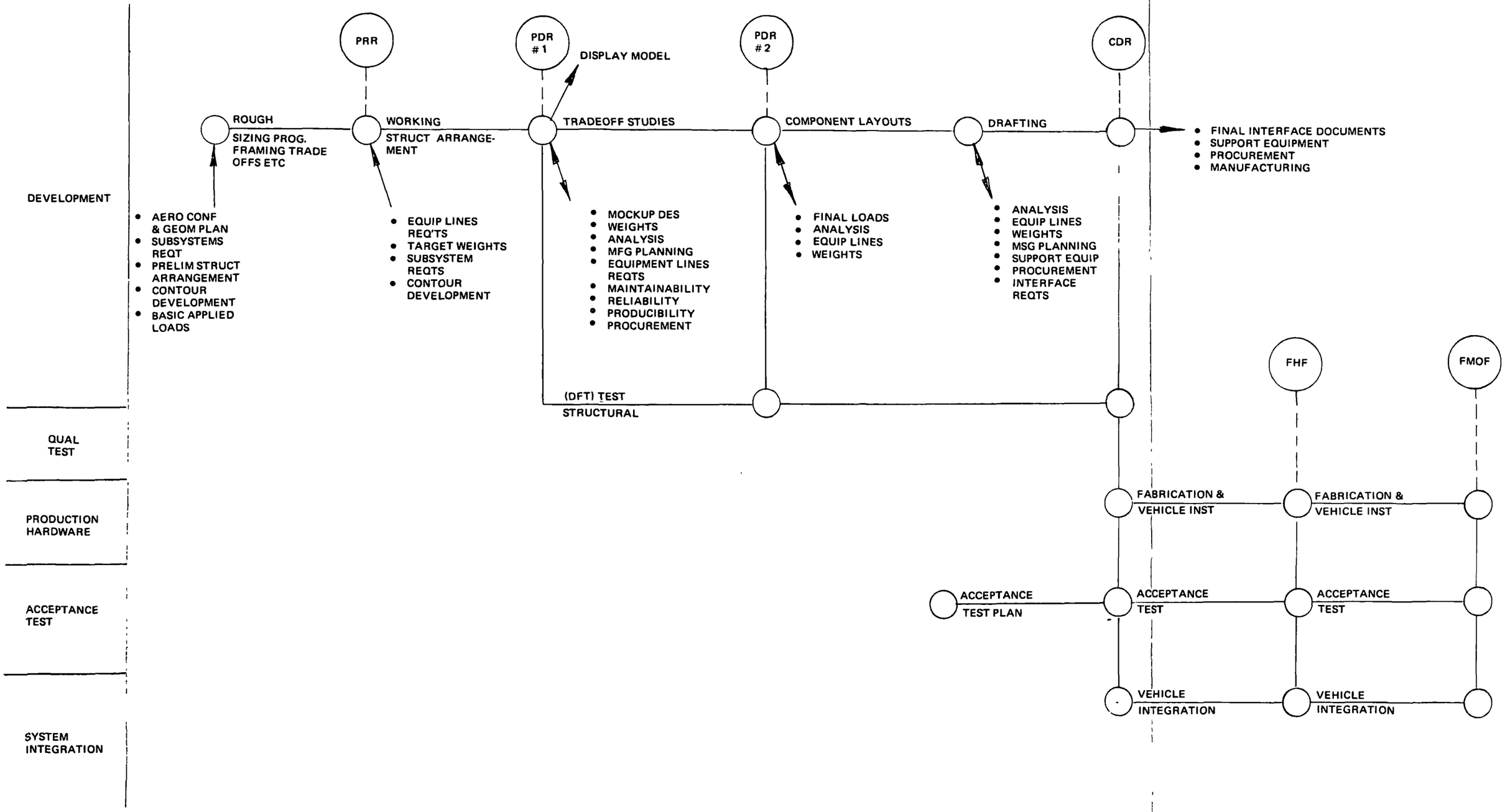

Fig. 3.1-3 Aerodynamic Surfaces Logic Network

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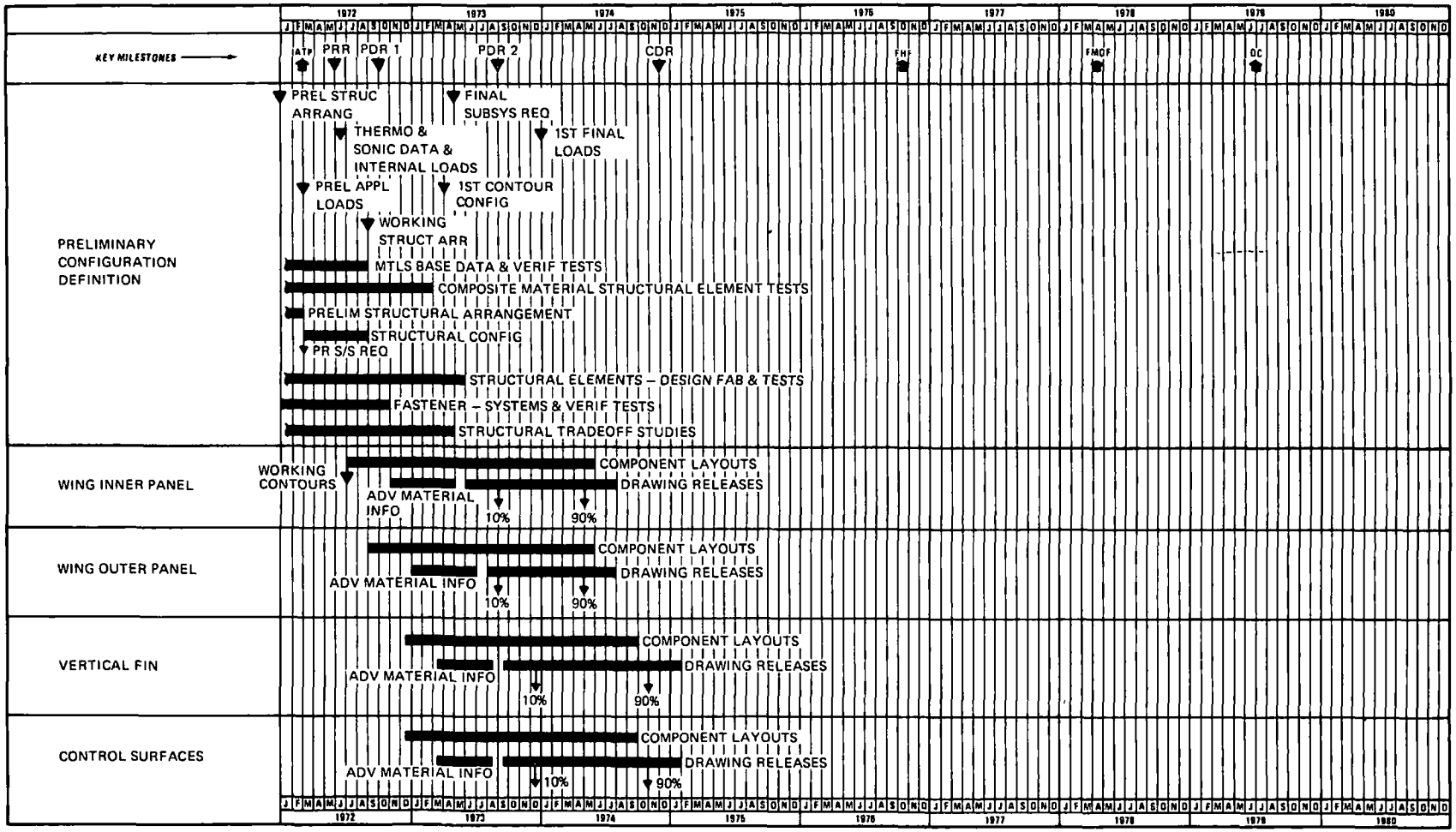

Fig. 3.1-4 Aerodynamic Surfaces Schedule

TABLE 3.1-1 SUBSYSTEM CERTIFICATION REQUIREMENTS

Certification Requirement	Certification Method						Level of Assembly				
					TEST						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
Certification requirement verify the strength, life and failure modes of the structure as follows:											
Wing Beam Elements	X				X		X				
Composite Materials Struct. Elements	X				X		X				
Wing Cover Element	X				X		X				
RCS Insulation Tests					X	X	X	X			
Wing Struct. Assy-Pos g (Temp/Load)						X		X			
Wing Struct. Assy-Neg g Load (End Boost Launch Condition)						X		X			
Vertical Fin Struct. Assy - Temp/Load						X		X			
Rudder Struct. Assy - Temp/Load						X		X			
Elevon Struct. Assy - Temp/Load						X		X			
Wing Fail-Safe Elements - Temp/Load					X	X	X	X			

TABLE 3.1-2 MAJOR COMPONENT LIST

COMP NO.	Component Description	Qty/ Vehicle	Weight Each, lb	Size Each sq. ft.	POWER EACH
	Wing - Center Section	1	3,615	2250	
	Wing - Outer Panel	2	16,888	1550	
	Elevons	2	5,921	415	
	Vertical Tail	1	3,355	736	
	Rudder	1	915	235	

TABLE 3.1-3 REQUIRED EQUIVALENT UNITS

Hardware Description	Required Equiv. Units
Flight Hardware Per Vehicle	1
Component Devel. & Qual Test	1/4
Integration Tests	
• Full Mission Simulation Laboratory	
• Integrated Avionics Test Laboratory	
• Flight Controls Hydraulic Test Laboratory	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	
Test Articles	
• Propulsion Test Article	0
• Structural Test Article	1*
Spares For Flight Test Program	0
Spares For 445 Flights	1**

*RH elevon not required for structural test.
**One elevon (RH & LH) and one rudder required for spares.

TABLE 3.1-4 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST HARDWARE

Item	Common	Potential Common	Not Common	Remarks
Structural materials		X		
Fasteners		X		
Hard attach points shall be provided for handling large components as well as the complete shuttle	X			
Evidence of operational damage shall be easily detectable at least one mission prior to failure	X			Development and use of NDE
Temperature range of materials	X			
Material development & qualification		X		
Joint concepts		X		
Hi temp sealing of doors and movable control surfaces		X		

TABLE 3.1-5 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

Item	Requirements
Support Equipment	Support Stands (Hor, Vert Erect.)
	Access Stands
	Slings, Dollies, Jacks
	Component Support Fixture (Install)
	Component Protective Devices
	Tools & Fixtures for Install.
	Rigging Devices
Software	None

TABLE 3.1-6 FACILITY REQUIREMENTS LIST

Title and Description	New	Exist.	Contr.	Gov
Floor space for element, assy, DVT, static, fatigue tests	X	X	X	

3.2 FUSELAGE

3.2.1 FUNCTIONAL DESCRIPTION

3.2.1.1 Fuselage

The present baseline orbiter fuselage structural configuration and internal tanks are shown in Fig. 3.2-1. It consists of four major modules: forward, mid, and aft sections and crew compartment.

- The fuselage provides internal stowage volume, structural support and an environmental envelope for:
  - Payload and deployment system or ferry package
  - Crew compartment
  - Main LO_2 tanks
  - OMS, EC, ACPS, ABPS, EPS tanks
  - Main rocket engines
  - Air breathing engines (located on cg to assure no effect on trim installed or removed)
  - OMS engines
  - ACPS engines
  - Nose landing gear
  - Deceleration chute
- In conjunction with body TPS, it protects these items from the thermal load and pressure effects of ascent and descent
- It supports the external LH_2 main tanks and provides the structural base for the wings, vertical fin, and orbiter/booster interstage fittings

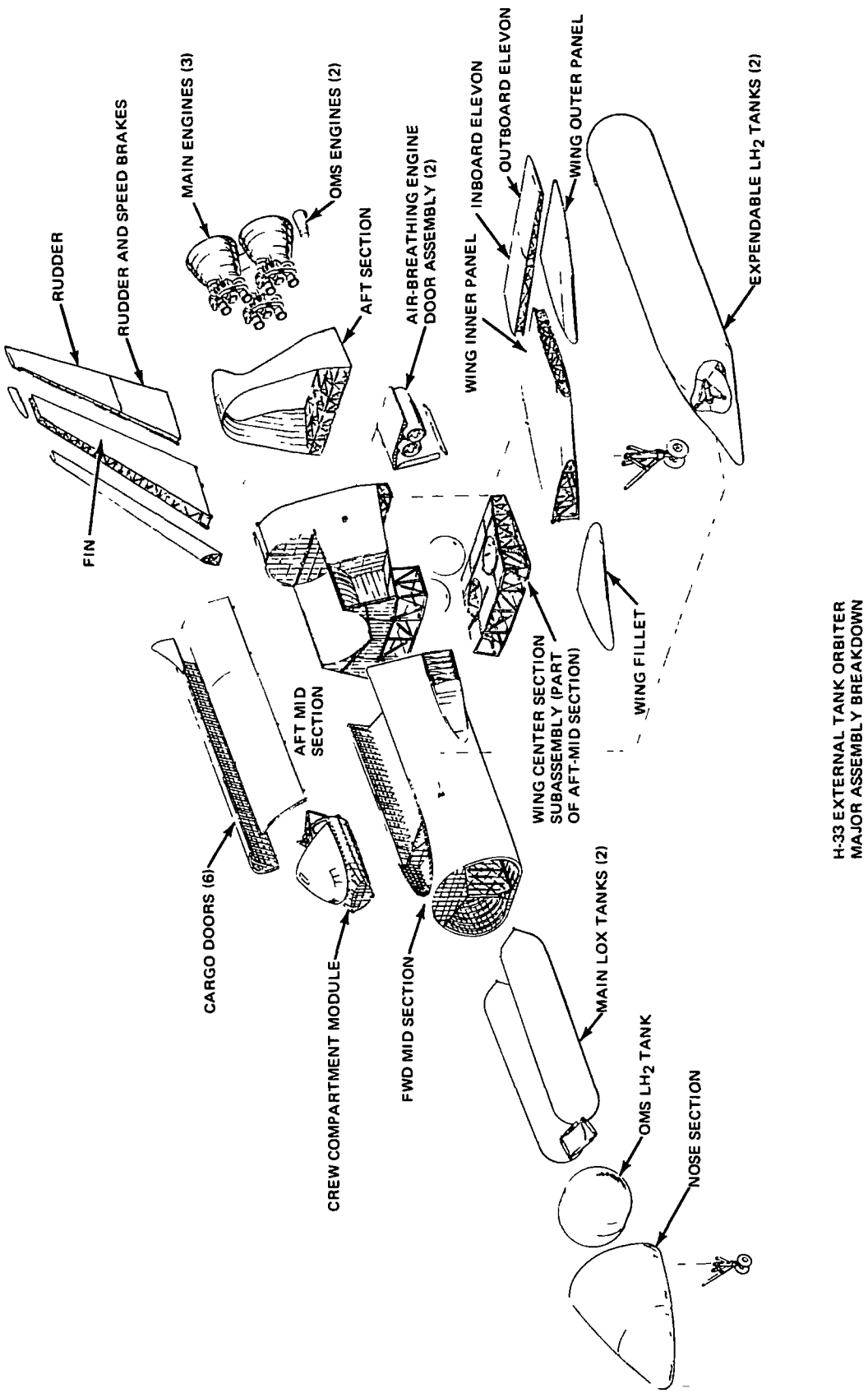

Fig. 3.2-1 Major Assembly Breakdown Drawing

- Crew compartment is pressurized at 14.7 psia maximum operating pressure of 990 cu ft volume, ECS controlled for two crew and two passengers and provides equipment stowage volume and support
- Its exterior shape is aerodynamically optimized for mission effectivity

3.2.1.2 Internal Tanks

3.2.1.2.1 Main LO_2 Injection Tanks

The primary function of the oxidizer tank shown in Fig. 3.2-2 include:

- Contain propellant to satisfy ΔV requirements
- Resist propellant loads caused by tank pressurization and hydrostatic head for mission life
- Prevent propellant sloshing and vortexing
- Transfer propellant flight loads to the basic fuselage structural shell
- Support propulsion subsystem equipment
- Prevent propellant leakage

3.2.1.2.2 OMS LH_2 and LO_2 Tanks

The OMS LH_2 and LO_2 tanks shown in Fig. 3.2-3 contain the cryogenic propellant necessary to:

- Provide ΔV for gross orbital maneuvers via the RL-10 engines
- Provide ΔV for attitude control via the ACPS engines
- Provide O_2 and H_2 for subsystem requirements

The OHMS tank shall also:

- Provide thermal protection of the cryogens to minimize boiloff for seven days
- Resist propellant loads caused by tank pressurization and hydrostatic head

3.2.1.2.3 ABPS JP-4 Tanks (Permanent and Ferry)

The ABES tank shown in Fig. 3.2-4 contains the propellant for the airbreathing engines and resists the propellant load caused by tank pressurization and hydrostatic head.

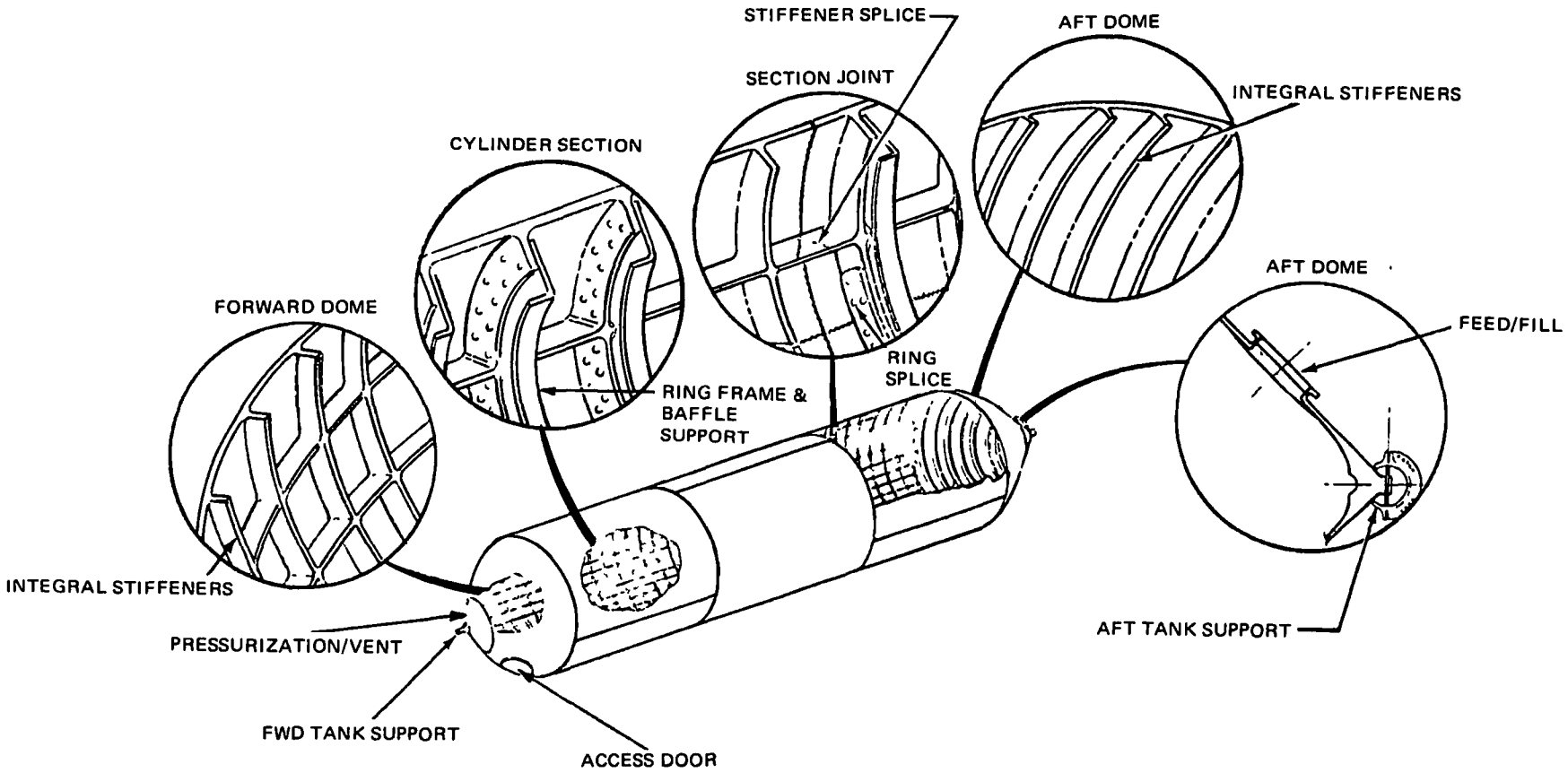

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Fig. 3.2-2 Injection LO_2 Tank

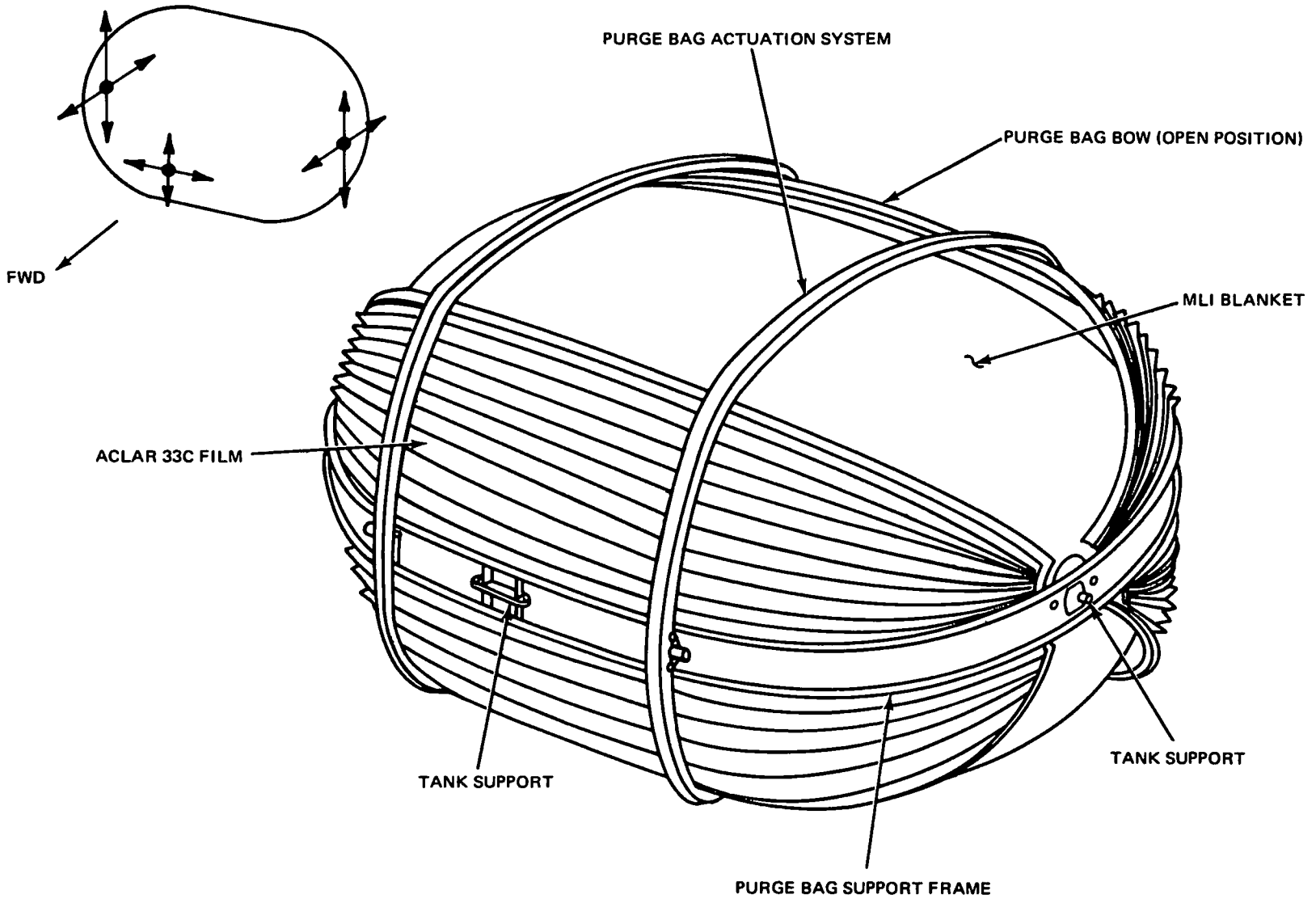
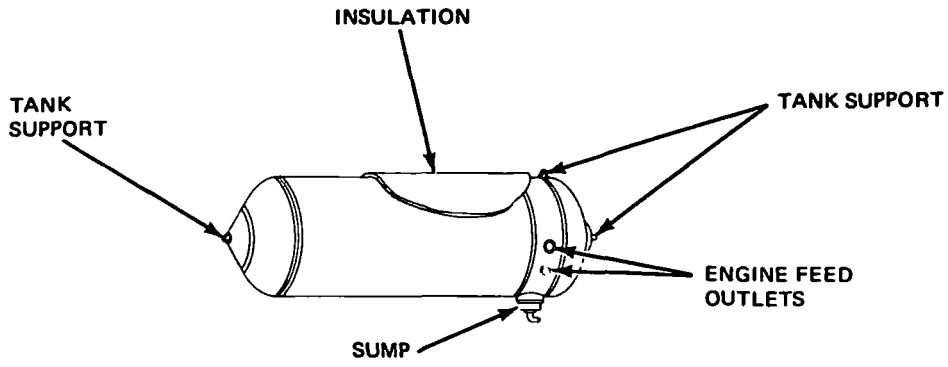
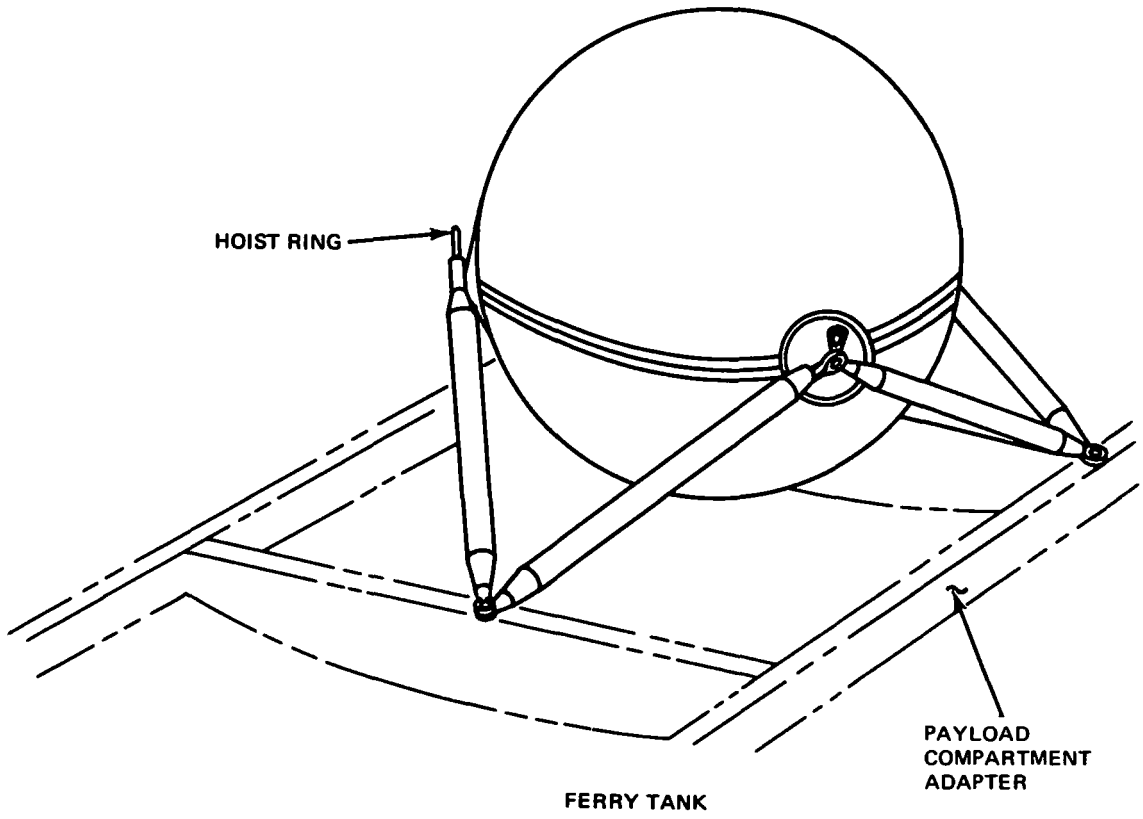


Fig. 3.2-3 OMS Liquid Hydrogen Tank



"GO-AROUND" TANK



FERRY TANK

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Fig. 3.2-4 ABPS JP-4 Tanks

3.2.2 PRINCIPLE FEATURES AND DESIGN CHARACTERISTICS

3.2.2.1 Fuselage

Principal features and design characteristics of the fuselage include:

- Slope and geometry of the windshield is designed to minimize thermals and retain optimum vision
- Conventional semi-monocoque titanium airframe structure employing longerons, bulkheads and stiffened shear panels. TPS mounted on standoffs outside the primary structure
- Payload compartment doors fabricated of titanium skin and stringers, containing space radiators
- Boron composite reinforced engine thrust structure
- A cylindrical crew module consisting of a forward crew compartment and an aft air lock module. Both are mechanically fusion welded, assembled of 2219 aluminum alloy sheet and machined 2219 longerons. The crew compartment contains six windows in a windshield assembly to provide crew visibility, and a pressurized aft hatch for access to the airlock module. The airlock module incorporates a side hatch for normal, emergency, and EVA ingress/egress and an aft hatch for ingress/egress to the payload compartment and possible EVA
- All exterior doors and access panels are part of the TPS

3.2.2.2 Internal Tanks

3.2.2.2.1 Main LO_2 Inspection Tanks

The principal features of the LO_2 tanks are:

- Integrally stiffened 2219 aluminum pressure shell
- End dome supports
- Tanks supported determinately at end domes with truss system
- Access to tank interior via removable cover
- Mechanized TIG weld joints in pressure shell

3.2.2.2.2 OMS LH_2 and LO_2 Tanks

- One LH_2 tank, cylindrical with spherical end domes, 13 ft dia x 18 ft long
- Two spherical LO_2 tanks, 8 ft dia
- Welded 2219 aluminum tank shell
- MLI blanket insulation with openable purge bag
- Three point tangent support

3.2.2.2.3 ABPS Tanks

- Permanent tank
  - 3 ft dia x 13 ft long
  - Spherical end domes with support cones
  - Welded 2219 aluminum
  - Integral sump compartment
  - External foam insulation
- Ferry Tank
  - 12 ft dia spherical tank
  - Welded of two 2219 aluminum hemi-spherical spinnings
  - Three point tangent support
  - Quick installations on payload adapter

3.2.3 RISK IDENTIFICATION AND RESOLUTION

Some prominent potential risks in the fuselage and internal tankage are identified as follows:

- Fuselage
  - Design for thermal stresses
  - Composites applications

- Mission life
- Windshield and windows
- Wing-fuselage intersection
- Cryogenic line feed integration
- Acoustic fatigue
- Corrosion prevention - sealants, etc.

● Tanks

- Mission life guarantee
- Safety
- Method of support (floating/integral)
- Cryogenic insulation
- Stress corrosion

3.2.3.1 Fuselage

Thermal stress efforts will be pursued with in-depth analysis, careful consideration of joints and joining techniques, extensive element verification testing, while selective use of TPS will minimize hot structure.

Risk in composite applications is resolved by correct selection of materials and proper utilization of their unique capabilities. Current and past programs under AF contract, such as wing optimization in cooperation with Northrop, and F-111 wing box component, the present production boron-epoxy faced F-14 stabilizer, the 1/3 scale NASA thrust structure, and strong in-house AD efforts, have developed outstanding competency in design and manufacturing in this field.

Mission life of the basic structure will be developed with broad use of fail safe and/or safe life design effectively proven in the Gulfstream II, E-2C, C-2A, etc. Use of standard non-destructive evaluation (NDE) techniques will support and monitor design success in addition to conventional visual inspection of almost the entire interior surface with direct viewing devices.

Optimized windshield and windows are vital to successful mission performance. Maximum reentry temperatures will be prevented from direct glass contact by a retractable or discardable metal shield. The basic outer panel, protecting against thermal and bird strike effects, is fused silica (quartz) currently used on the LM in the soft state, and also derived from the SST technology. This panel is backed by tempered inner glass pressure panes with tempered inner windows for redundancy. Multi-layer UV and IR rejection coatings, also reflecting light energy and glare, will be supplemented with electrical defogging and a rain removal system. Extensive development testing will accompany the design progress.

The wing-to-fuselage intersection will be eliminated as a risk area with in-depth design and analysis and heavily supplemented and verified with development testing.

Cryogenic feed line insulation is a vital area that will receive extensive material selection and development testing drawing heavily on Apollo background.

Acoustic fatigue represents a very high risk because of mission life requirements. Extensive background gained on the A-6A, EA-6B, Gulfstream II, F-111 and F-14 will be utilized to refine the design, and broad based development testing will be effectively employed to verify the optimum configurations.

Corrosion, due to the galvanic action of dissimilar metals and a moisture environment, will be minimized by the use of faying surface sealants and surface protective coating. Stress corrosion, although not a current problem with the contemplated titanium alloys, will be closely monitored if corrosion threshhold stress valves are incorporated.

3.2.3.2 Internal Tanks

A high risk area is fracture control of tanks. Unique features of the H-33 configuration minimize some associated risks. Internal tanks on the H-33 are simply and quickly removable. This allows a more thorough, extensive, and reliable NDE to be accomplished apart from the basic vehicle thus removing any flight readiness constraint. Element, component, and assembly testing will add additional confidence for complete reusability of tanks.

Safety requirements are heavily associated with the mission life requirements of the tanks. Here again the unique features of the H-33 configuration contribute to meeting the high safety standards required. Specific design approaches, i.e., leak rather than rupture and crack retardation, will be explored and tested as required to further enhance the safety aspects of all tanks.

Possible dynamic and/or high load factors effects with floating tank supports constitute a risk item. This risk area will be addressed by an extensive analytical effort and tank supports will be designed to eliminate this condition.

Insulation design for the OMS tanks will utilize the Apollo technology and current orbiter technology development contracts combined with the test program described in subsequent sections.

Valuable experience gained on the LM, E-2A, A-6A and other programs will form the backbone of a stress corrosion prevention program for aluminum alloys. Material selection, joint details and fabrication and assembly techniques will be mandated based upon best established engineering practices.

3.2.4 CERTIFICATION TEST PROGRAM

3.2.4.1 Fuselage

All testing will be preceded by in-depth finite element analysis derived through the IDEAS program used effectively with considerable saving in engineering effort on the F-14.

Sophisticated test requirements have also been efficiently developed and used in the verification of F-14 strength.

The following tests are representative of the planned effort:

- Aft drag attachment interstage support elements - Solution of the risk problem of high drag and pulse loads resulting from critical boost conditions will be verified by an assembly fatigue test
- Forward interstage attachment support elements - Similarly, booster induced loads also create critical loads on the forward interstage fitting and support structure. A fatigue program of pulse and separation loads will be applied to verify this design

- Windshield elements - An optimized design of the windshield-to-support structure preceded by in-depth transparency evaluations and selections will test the interface for critical pressure and thermally induced loads occurring during reentry. An actual transient temperature-time history sequence will be used rather than the inadequate standard soak test

- ABPS Integrated Deployable Support and Associated Elements - Deployment of the air breathing propulsion subsystem after reentry will necessitate a DVT to verify structural stability of the engine support platform and engine mounts together with associated deployable features such as feed lines, starter lines, hydraulic actuation mechanisms, locking devices seals and check out provisions under simulated thermal and mechanical loads

- Thrust Structure Elements - Composite material mated with conventional alloys in optimized structural shapes for critical boost thrust loads will be verified by test. This is supported by techniques and methods currently in use in the 1/3 scale thrust structure contract with NASA

- Engine Mounts and Elements - Load path determination for engine thrust loads will be verified by test of the multibeam, tri-engine support arrangement. Element tests of attachment points to main-frame-longeron connections will precede component level testing

- Wing-to-Fuselage Attachment Elements - Wing-to-fuselage connection tests will verify the redundant analysis. The resulting experimentally determined load distribution will correlate the analytically predicted internal stress levels

- Payload Door and Radiator Elements - The design of the latching mechanism and structural alignment under load deflection of the 65 ft long by 28 ft circumference "clam-shell" payload doors will be verified under critical loads and environmental conditions

- Composite Materials Structural Elements - DVT to determine design allowables for various splice designs of composite materials bonded to structural alloys will be conducted on the element level early in the program to verify design assumptions

3.2.4.2 Internal Tanks

Recognizing the high risks involved in tank design and life assurance, this test sequence is presented to guarantee maximum effectiveness and reliability of flight article tankage. Previous in-depth experience on successful tank programs such as the LM propellant tank, LM supercritical helium tank and air breathing fuel tanks on military/commercial aircraft is the basis for this logical, technically competent and cost conscience test program.

These are four major program phases:

- Element Testing - Derive design data for all mission environments; including fracture mechanics testing and thermal stress element tests
- Development Testing - Higher assembly testing including slosh testing and insulation thermal performance evaluation
- Qualification Testing - Demonstrating tankage mission life capability by exposure to strength and fatigue tests
- Acceptance Testing - Testing to confirm analytically derived mission life of a tank

The test program is formulated to satisfy the specific mission requirements of each tank, thus producing a unique test sequence for each tank. A summary of testing implementation for all tanks is presented in Table 3.2-1. The rationale for test and acceptability methods is explained in the following tank subheadings.

The qualification program is composed of two parts:

- Strength qualification verifies the structural integrity of the tank to one mission cycle at qualification levels
- Fatigue qualification verifies fatigue life of the tank by exposure to mission life multiplied by scatter factor cycles

3.2.4.2.1 Main LO_2 Injection

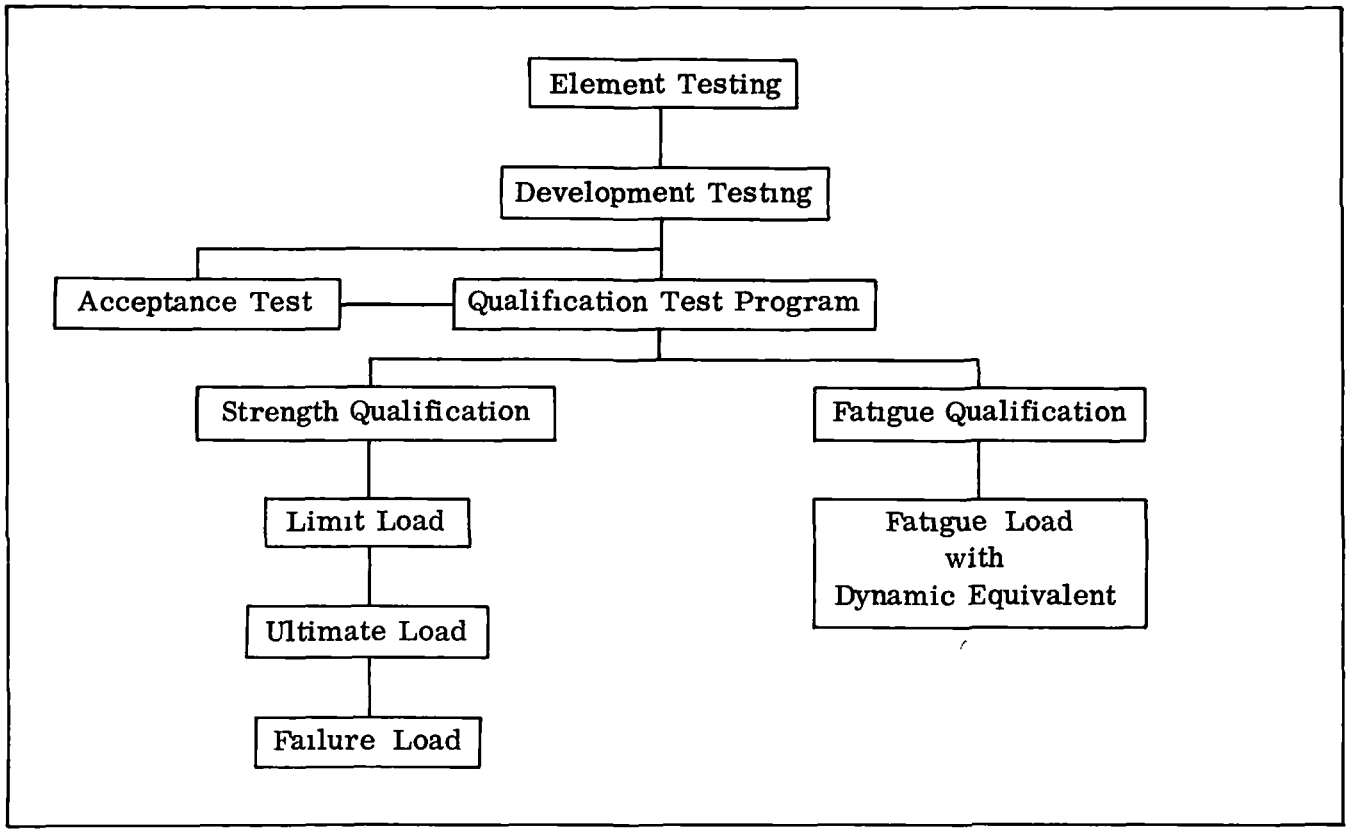
Grumman's floating/removable LO_2 tank design requires no insulation and only a purge environment for the ground hold period. Although the baseline design is a bare tank,

TABLE 3.2-1 SUMMARY OF TANK TESTING IMPLEMENTATION

		MAIN LO_2	OMS LH_2	OMS LO_2	ABPS (Perm)	ABPS (Ferry)
Element Testing		• Provide design data on tank materials • Element testing apparatus			Not Required	
Development Testing		• Tank model on shaker system using referee fluid • Slosh Rig	• Insulation evaluation using full scale boiler plate tank (referee fluid) • Shaker system • Vacuum Chamber • Functional Tests • Propulsion Test Facility		Not Required	
Acceptance Test		• LN_2/GN_2 pressurization of tank sections • Test stand with purge shroud	• Ambient gas pressurization of tank without insulation • Test Shroud • Thermal performance using cryogen • Vacuum Chamber		• Pressurization (Inhibited Water) • Hydrostatic tank	
QUALIFICATION TESTING	Vibration Test	Equivalent test performed as part of pressure cycle test	• Vibrate using mass representation @ cryo T & P • Shaker system		• Vibrate using referee fluid • Shaker system	
	Limit Load Test	• Immerse in inhibited water with applied loads • Hydrostatic Facility	• Pressurization and g load using LH_2 • Acceleration Track	• Pressurization and g load using LN_2 • Acceleration Track	• Pressurization and g load using referee fluid • Acceleration track	
	Pressure Cycle Test	• Immerse in inhibited water with applied dynamic/static load and pressure cycles • Hydrostatic Facility	• Pressurization and g load using LH_2 • Acceleration Track	• Pressurization and g load using LN_2 • Acceleration Track	• Pressurization and g load using referee fluid • Acceleration track	
	Ultimate Load	• Immerse in inhibited water with applied ultimate pressure • Hydrostatic Facility	• Ultimate loads applied at mission conditions (use LH_2) • Acceleration Track	• Ultimate loads applied at mission conditions (use LN_2) • Acceleration Track	• Ultimate Pressure application using referee fluid • Acceleration track	
	Failure Test	• Immerse in inhibited water and pressurize to burst • Hydrostatic Facility				
	Thermal Performance	Performed as part of propulsion test article program	• Ground Hold/Vacuum Performance (using LH_2) • Vacuum Chamber	• Ground Hold/Vacuum Performance (using LN_2) • Vacuum Chamber	Not required	

Grumman is extremely conscious of the possible savings in weight and increased safety by using overwrap techniques and will study these possibilities further.

TABLE 3.2-2 MAIN LIQUID OXYGEN TANK TEST PROGRAM



a. Element Testing

The element test program will provide design information on tank materials which include fracture mechanics data, thermal stress fatigue effects and material selections to ensure LO_2 compatibility. The detrimental effect of thermal stresses pertinent to LO_2 tank design is small and can be fully evaluated during the element testing phase.

b. Development Testing

In order to keep slosh effects to an acceptable minimum, a slosh rig will be configured to demonstrate the results of the analytical efforts. To investigate possible vortex effects, a series of outflow tests will also be performed.

c. Acceptance Testing

A test program which provides a practical and effective method of testing the LO_2 tank in sections because of its unique variable thickness wall design has been formulated. It is proposed that two tanks in three sections each go through the qualification test series in separate pieces. This method enables demonstration of different design allowables of the various section. The three sections will be proof tested (acceptance) separately. The acceptance test of the flight version is performed as the tank is built up. The lower section is first tested to its proof pressure using a weld-on test fixture. After NDE and removal of the fixture the next flight section is welded on with its weld-on test fixture. This section is now tested to the proof pressure of the mid-section. This procedure is repeated until the tank assembly is tested to the proof pressure of the uppermost section. Acceptance testing will occur at cryogenic temperatures (LN_2).

d. Qualification Testing

Technical capability to ratio tank design stress from ambient to cryogenic temperature allows all strength tests (see Table 3.2-1) to be performed in a hydrostatic test facility. Since the tank will be tested in sections (each section with an attached test cover), a normal vibration test is not meaningful. Equivalent static cyclic loading will simulate the vibration effect. Bending moments due to sectioning and launch loads will be transmitted by use of hydraulic loading devices and internal water pressure. The fatigue qualification test is a repetitive pressure load cycling with a simultaneous cyclical external load application.

Overall performance and effects of the vehicle purge environment will be evaluated as part of the Propulsion Test Article operation. Effects due to acoustical vibration will also be evaluated using data from the PTA firings.

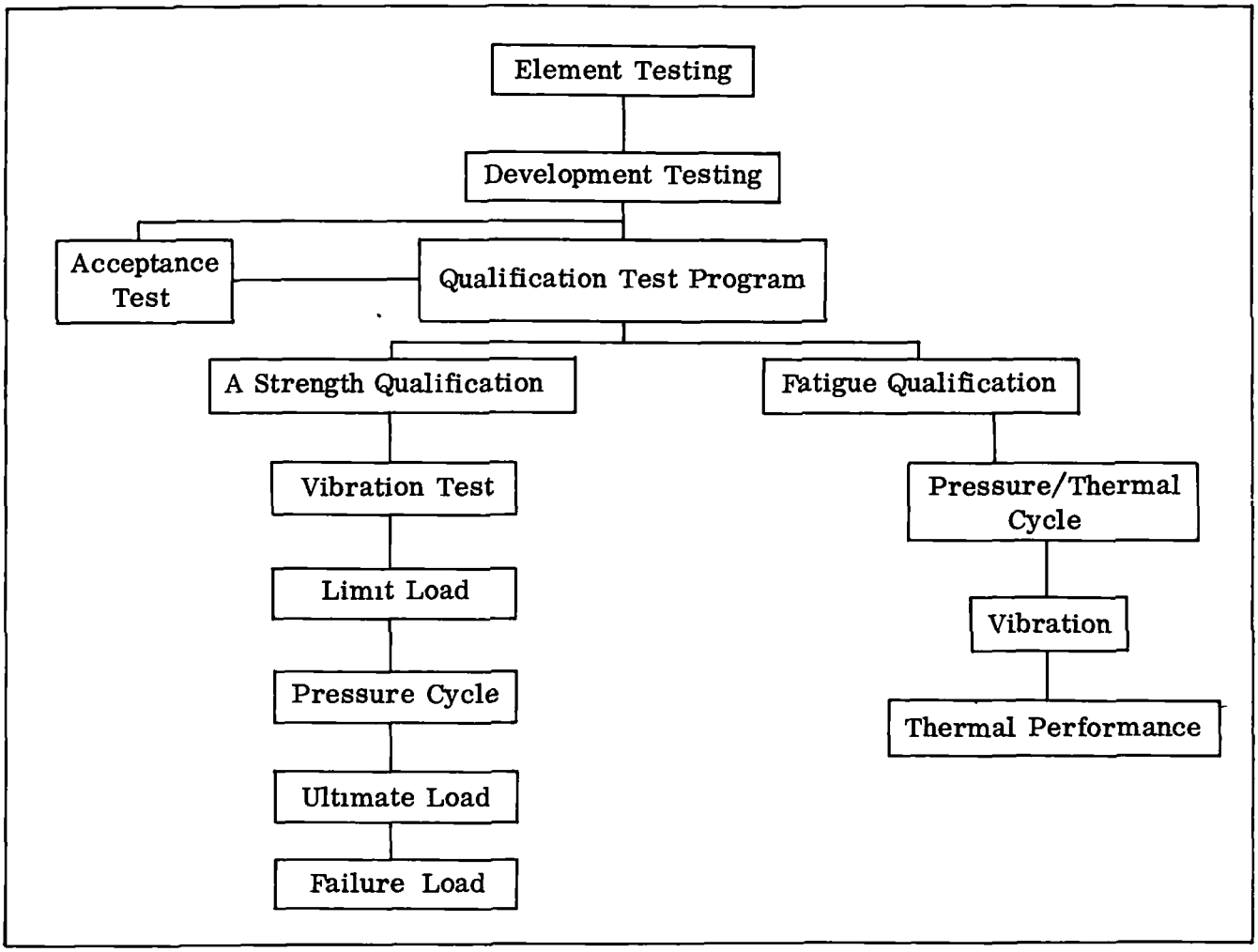
3.2.4.2.2 LH_2 and LO_2 OMS Tanks

The baseline design concept for OMS tankage is an aluminum tank wrapped with multilayer insulation and purge cover. Tank standoffs provide a purge gas flow passage adjacent to the cryogen tank surface. The OMS LH_2 tank has an additional layer of foam insulation sprayed onto the cryogen tank in order to increase ground hold capability. The proposed

tank support system (three point support) is composed of fiberglass thermal isolators (opposite ends) and S-glass isolators. Internal tank components include a helium tank (for launch/orbit and de-orbit purging), expulsion system (screens) and fluid sensors.

Since the mission objectives and design concept of both OMS Tanks (LH_2 and LO_2) are similar, common usage of facilities will be utilized wherever possible.

TABLE 3.2-3 OMS TANK TEST PROGRAM
(SIMILAR FOR LH_2 AND LO_2)



a. Element Testing

This encompasses all testing that concerns design data for tank material properties. LH_2 and LO_2 temperatures are required in most cases (LHe and LN_2 will be used).

When compatibility questions arise the real fluids are required. Typical design information that will be determined during this period is:

- Thermal conductivity of full scale thermal isolation tank support materials
- Shear strength of bonds at mission temperatures and as a consequence of cyclic loading
- Crack propagation tests
- Fatigue life of fiberglass supports
- Insulation effectiveness

b. Development Testing

During the development phase, a boiler-plate tank will be manufactured to demonstrate the acceptability of the proposed tank design. The reasons leading to this mode of operation are:

- The insulation lay-up techniques, particularly around thermal isolators can be investigated
- The clam-shell purge must have a full scale DVT (this includes simulated mission operation)
- Tank thermal performance (particularly heat leak along tank supports and fiberglass cone isolators) is very difficult to evaluate with anything other than full scale
- Data on the insulation evacuation transient can be obtained
- Purge requirements can be formulated
- Insulation deterioration due to cumulative mission vibration and repeated environmental exposure (vacuum as well as launch purge) can be investigated
- Repair and inspection techniques can be formulated

A false inner shell or volume filler can be added inside the boiler plate tank to reduce cryogen consumption.

c. Acceptance Testing

The acceptance test sequence of all OMS tanks includes both a proof pressure test and a thermal performance demonstration. The proof test occurs after all internal tank components have been installed and final closure has been made but prior to insulation buildup. After NDE procedures has been completed, the insulation will be installed and the purge bag mounted. The tank assembly will now be given a thermal performance test simulating ground hold and launch boost/orbit operation. The test facility must be a vacuum chamber having vehicle similitude with respect to flowing gases and environment. Also important is the pumping capability in order to simulate the pressure transient. LH_2 and LN_2 (substitute for LO_2) will be used as test fluids.

d. Qualification Tests

The tank assemblies of each type (LH_2 and LO_2 OMS) will be required for the qualification test program. All testing will be performed at cryogenic temperature and mission pressures with the exception of the failure demonstration (see Table 3.2-1). The vibration test will be performed using a mass representation for LH_2 and LN_2 substituting for LO_2. A feasible method of attaining the required g loading on the tank is the use of the proposed acceleration track.

Because of the extreme risk category of the OMS tankage, the fatigue qualification demonstration is very important. It is proposed to pressure/thermal cycle the tank repeatedly for the mission life (number of missions x scatter factor). At the conclusion of this series the tank assembly will be vibrated. Subsequent to that a test which demonstrates acceptable thermal performance at the conclusion of mission life will be performed. This test will be equivalent to the acceptance procedure. Note that NDE will follow the tank throughout the program.

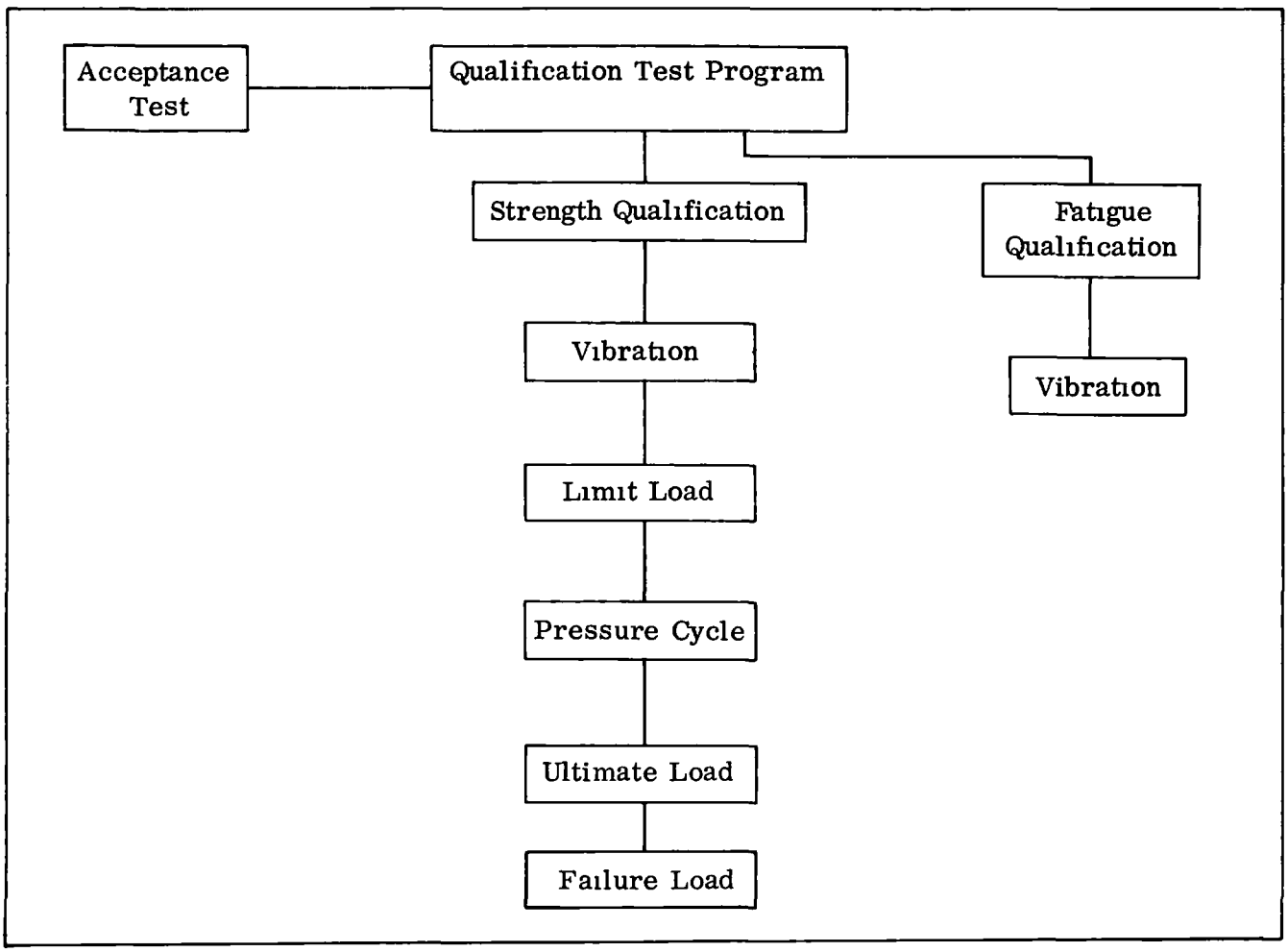
Functional testing of the internal tank components will be demonstrated as part of the OMS Engine Test Program.

3.2.4.2.3 ABPS JP-4 Tanks (Permanent and Ferry)

A developmental program is not required on the ABPS tanks. Established state-of-the-art knowledge on airplane tankage and GAC extensive previous experience in this area makes this unnecessary.

Two tanks will be required in the qualification program. All testing will be performed using a referee fluid (inhibited water).

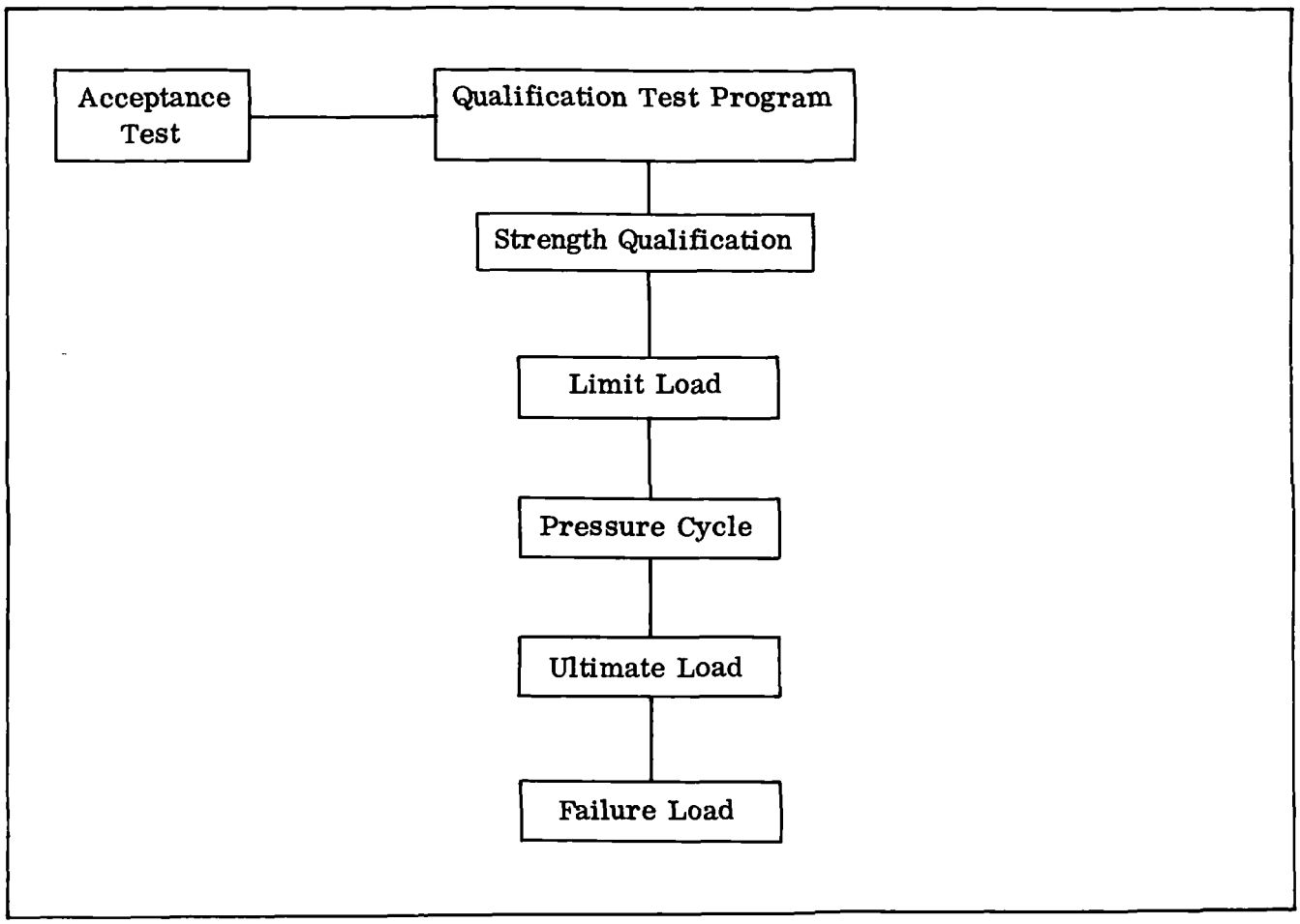
TABLE 3.2-4 PERMANENT TANK TEST PROGRAM



The acceptance test and failure load demonstration will be performed in a hydrostatic tank. To provide the required g loading for strength tests an acceleration track will be used. Vibration tests in three axis will be performed on a mechanical shaker.

A high degree of design conservatism will eliminate most test requirements. The qualification test will take the form of strength tests because of the limited ferry flight regime.

TABLE 3.2-5 ABPS FERRY TANK TEST PROGRAM



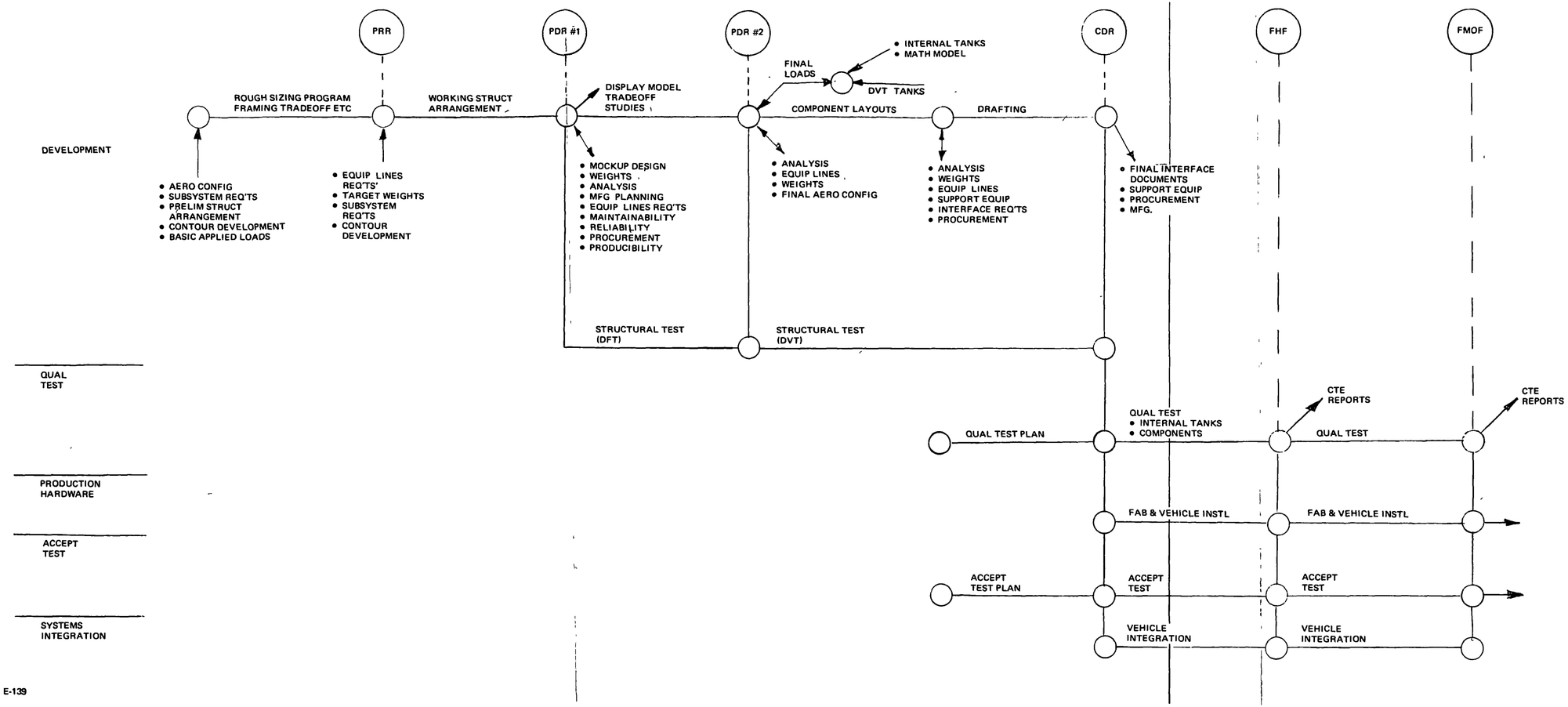


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Fig. 3.2-5 Fuselage Logic Network

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BOEING

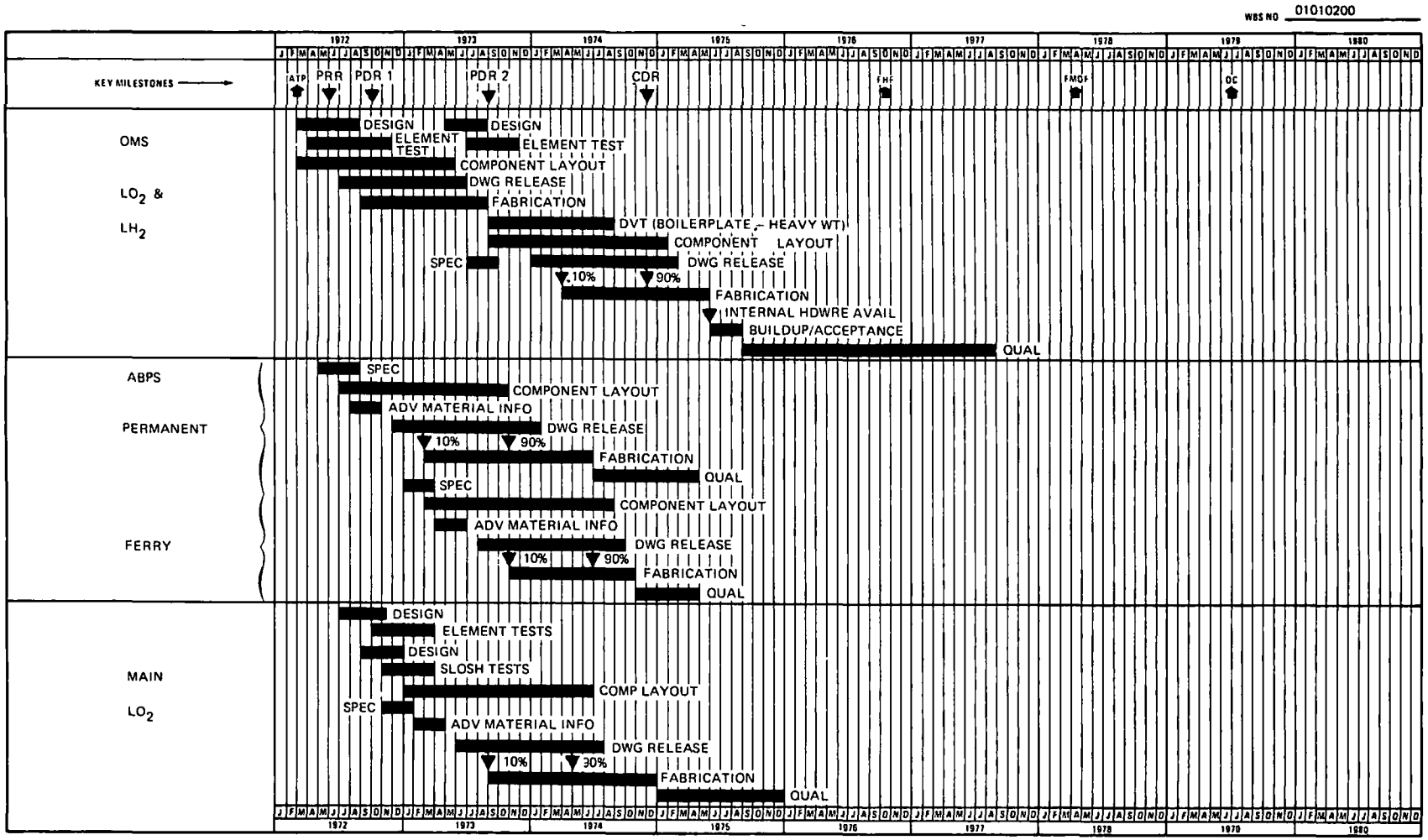

Fig. 3.2-6 Fuselage and Internal Tanks Schedule

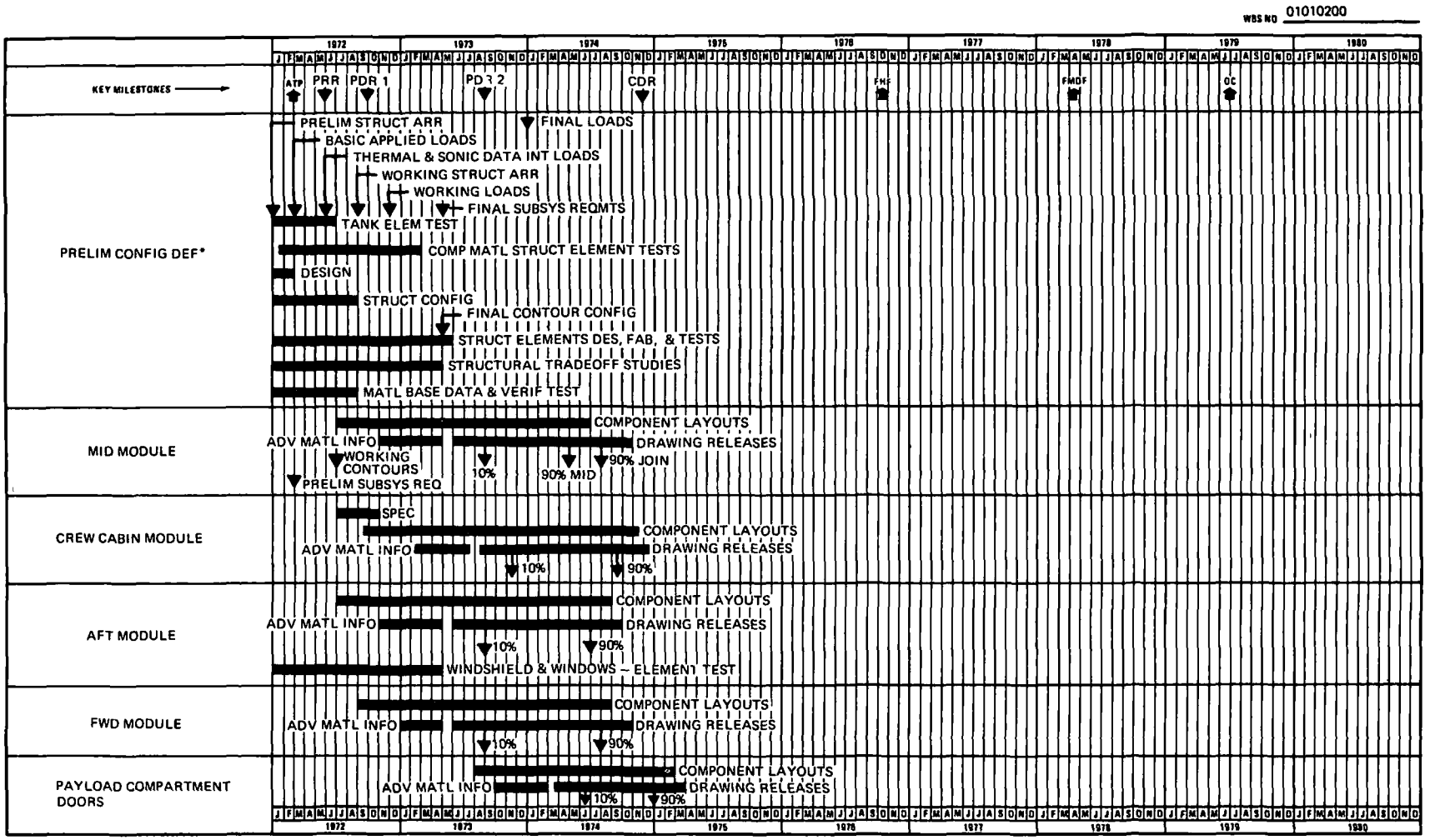

Fig. 3.2-7 Fuselage and Internal Tanks Schedule (Sheet 1 of 2)

TABLE 3.2-6 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 1 of 4)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subassembly	Comb. Subassembly	Flight Vehicle
Engine Mountings	X				X	X	X				
Cabin Press PRF Test	X					X		X			
Drag Chute Fitting Element Test	X				X	X	X	X			
Payload Support Struct. Element Tests	X				X	X	X				
ACPS Insulation Tests	X				X	X	X	X			
Fuselage - Max Bending (Max G)	X					X					X
Fuselage - Max Torsion (Max $Q\beta$)	X					X					X
Fuselage - Seat Support Tests	X					X		X			
Fuselage - Door and Access Panels	X					X		X			
Fuselage - Fail Safe Tests	X					X					X
Verify the strength or life or thermal performance etc.:											
Wing-To-Fuse Attach Elements	X				X		X				
Aft Drag Attach Interstage L. G. Suppt Element					X	X		X			
Fwd Interstage Attach & L. G. Suppt Element					X	X		X			

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TABLE 3.2-6 SUBSYSTEM CERTIFICATION REQUIREMENTS

(Sheet 2 of 4)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
Windshield Elements					X	X	X	X			
ABPS Support Elements					X	X	X	X			
Payload Doors & Radiator Element	X				X		X				
Composite Materials Struc. Elements	X				X		X				
Thrust Struct. Element	X				X		X				
Main LO_2 Tank Element	X				X		X				
Main LO_2 Tank Slosh Baffle & Dynamic	X	X			X			X			
Main LO_2 Acceptance								X			
Main LO_2 Limit Load						X		X			
Main LO_2 Ultimate Load						X		X			
Main LO_2 Failure Load						X		X			
Main LO_2 Fatigue Spectrum						X		X			
OMS LO_2 Tank Element	X	X			X		X				
OMS LO_2 Tank Full Scale Thermal Performance	X				X			X			
OMS LO_2 Tank Acceptance								X			

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TABLE 3.2-6 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 3 of 4)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
OMS LO_2 Tank Vibration (Strength)						X		X			
OMS LO_2 Tank Limit Load						X		X			
OMS LO_2 Tank Pressure/Load Cycle (Strength)						X		X			
OMS LO_2 Tank Ultimate Load						X		X			
OMS LO_2 Tank Failure Load						X		X			
OMS LO_2 Tank Pressure/Load Cycle (Fatigue)						X		X			
OMS LO_2 Tank Vibration (Fatigue)						X		X			
OMS LO_2 Tank Thermal Performance						X		X			
OMS LH_2 Tank Element	X	X			X		X				
OMS LH_2 Tank Full Scale Thermal Performance	X				X			X			
OMS LH_2 Tank Acceptance								X			
OMS LH_2 Tank Vibration (Strength)						X		X			
OMS LH_2 Tank Limit Load						X		X			
OMS LH_2 Tank Pressure/Load Cycle (Strength)						X		X			
OMS LH_2 Tank Ultimate Load						X		X			

TABLE 3.2-6 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 4 of 4)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
OMS LH_2 Tank Failure Load						X		X			
OMS LH_2 Tank Pressure/Load Cycle (Fatigue)						X					
OMS LH_2 Tank Vibration (Fatigue)						X					
OMS LH_2 Tank Thermal Performance						X					
ABPS Tank (Perm) Acceptance								X			
ABPS Tank (Perm) Vibration (Strength)						X		X			
ABPS Tank (Perm) Limit Load						X		X			
ABPS Tank (Perm) Pressure Cycle						X		X			
ABPS Tank (Perm) Ultimate Load						X		X			
ABPS Tank (Perm) Failure Load						X		X			
ABPS Tank (Perm) Vibration (Fatigue)						X		X			
ABPS Tank (Ferry) Acceptance								X			
ABPS Tank (Ferry) Limit Load						X		X			
ABPS Tank (Ferry) Pressure Cycle						X		X			
ABPS Tank (Ferry) Ultimate Load						X		X			
ABPS Tank (Ferry) Failure Load						X		X			

TABLE 3.2-7 MAJOR COMPONENT LIST

Component Description	Qty/ Vehicle	Weight Each	Size Each cu ft	Power Each
Fwd - Section	1	4748	See Dwg.	--
Mid - Section	1	26,730		--
Aft - Section	1	8604		--
Cabin	1	2585		--
Main LO_2 Injection Tanks	2	8858	4125	--
OMS LO_2	2	375	437	--
OMS LH_2	1	1785	910	--
ABPS (Permanent)	2	TBD	--	--

TABLE 3.2-8 REQUIRED EQUIVALENT UNITS (Sheet 1 of 6)

SUBSYSTEM: Fuselage (Fwd., Mid, & Aft Sect.)

Hardware Description	Required Equiv. Units
Flight Hardware per Vehicle	1
Component Devel & Qual Test	1/4
Integration Tests	
• Full Mission Simulation Lab	
• Integrated Avionics Test Lab	
• Flight Controls Hydraulic Test Lab	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	
Test Articles	
• Propulsion Test Article	2/3*
• Structural Test Article	1
Spares for Flight Test Program	0
Spares for 445 Flights	0

*Refer to Sections 9 and 10 for a detailed description of the PTA.

TABLE 3.2-8 REQUIRED EQUIVALENT UNITS (Sheet 2 of 6)

SUBSYSTEM: Fuselage (Main LO_2 Tank)

Hardware Description	Required Equiv. Units
Flight Hardware per Vehicle	1 LH & 1 RH
Component Devel & Qual Test	1 (Qual) 1 (Element tests) .5 (Slosh)
Integration Tests	
• Full Mission Simulation Lab	
• Integrated Avionics Test Lab	
• Flight Controls Hydraulic Test Lab	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	
Test Articles	
• Propulsion Test Article	1
• Structural Test Article	0
Spares for Flight Test Program	0
Spares for 445 Flights	1

TABLE 3.2-8 REQUIRED EQUIVALENT UNITS (Sheet 3 of 6)

SUBSYSTEM: Fuselage (LH_2 OMS Tank)

Hardware Description	Required Equiv. Units
Flight Hardware Per Vehicle	1
Component Devel & Qual Test	1 (Element) 2 (Qual) 1 (DVT)
Integration Tests	
• Full Mission Simulation Lab	
• Integrated Avionics Test Lab	
• Flight Controls Hydraulic Test Lab	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	
Test Articles	
• Propulsion Test Article	1*
• Structural Test Article	0
Spares for Flight Test Program	0
Spares for 445 Flights	1

*OMS Integrated Test Article

TABLE 3.2-8 REQUIRED EQUIVALENT UNITS (Sheet 4 of 6)

SUBSYSTEM: Fuselage (LO_2 OMS Tank)

Hardware Description	Required Equiv Units
Flight Hardware per Vehicle	1 RH & 1 LH
Component Devel & Qual Test	1 (DVT) 1 (Qual)
Integration Tests	
• Full Mission Simulation Lab	
• Integrated Avionics Test Lab	
• Flight Controls Hydraulic Test Lab	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	
Test Articles	
• Propulsion Test Article	1*
• Structural Test Article	0
Spares for Flight Test Program	0
Spares for 445 Flights	1

*OMS Integrated Test Article

TABLE 3.2-8 REQUIRED EQUIVALENT UNITS (Sheet 5 of 6)

SUBSYSTEM: Fuselage (ABPS Permanent))

Hardware Description	Required Equiv. Units
Flight Hardware per Vehicle	1
Component Devel & Qual Test	2
Integration Tests	
• Full Mission Simulation Lab	
• Integrated Avionics Test Lab	
• Flight Controls Hydraulic Test Lab	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	
Test Articles	
• Propulsion Test Article	
• Structural Test Article	
Spares for Flight Test Program	0
Spares for 445 Flights	1

TABLE 3.2-8 REQUIRED EQUIVALENT UNITS (Sheet 6 of 6)

SUBSYSTEM: Fuselage (ABPS (Ferry))

Hardware Description	Required Equiv Units
Flight Hardware per Vehicle	1
Component Devel & Qual Test	1
Integration Tests	
• Full Mission Simulation Lab	
• Integrated Avionics Test Lab	
• Flight Controls Hydraulic Test Lab	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	
Test Articles	
• Propulsion Test Article	
• Structural Test Article	
Spares for Flight Test Program	
Spares for 445 Flights	

TABLE 3.2-9 BOOSTER/ORBITER COMMONALITY CANDIDATES LIST DESIGN

Item	Common	Potential Common	Not Common	Remarks
Universal hard attach points shall be provided for handling large components as well as the complete orbiter	X			ASSC Study Control Document, dated Sept. 1970
Temperature range of materials	X			
Material Development & Qualification		X		
Joint Concepts		X		
Door and hatch sealing		X		
Hi Temp cavity sealing		X		
Cryogenic tank sealing		X		
Internal Cryogenic Tank Materials		X		
Structural Materials		X		
Fasteners		X		
Various detail parts or sub-assemblies		X		

TABLE 3.2-10 SUBSYSTEM SUPPORT EQUIPMENT/ SOFTWARE REQUIREMENTS (Sheet 1 of 7)

Item	Requirements
Vehicle Assembly Support Equipment	Support Stands (Hor & Vert Erect.) Access Stands Slings, Dollies, Jacks Component Support Fixture (Install.) Component Protective Devices Tools & Fixtures for Install. Rigging Devices
Software	None
Fatigue Rig Support Equipment	(May be common for OMS LH_2 and LO_2 Tanks) GN_2 Support Equipment GHe Support Equipment GH_2 Support Equipment LH_2 Support Equipment LN_2 Support Equipment Test Instrumentation Data Recording Equipment NDE Support Equipment Test Fixtures Safety Equipment
Software	Programs for: Data Reduction Thermal/Pressure Cycle Transient

TABLE 3.2-10 SUBSYSTEM SUPPORT EQUIPMENT/
SOFTWARE REQUIREMENTS (Sheet 2 of 7)

Item	Requirements
Hydrostatic Test Facility	(Can be common for ABPS (permanent and Ferry) and OHS LH_2 and LO_2 Tanks.)
Support Equipment	Water Supply
	Water Purification Support Equipment
	Water Pressurization
	GN_2 Support Equipment
	GHe Support Equipment
	Test Instrumentation
	Hydraulic Controls (Loading)
	NDE Support Equipment
	Test Data Recording Consoles
	Test Fixtures
	Test Article Handling/Transport Equipment
Software	None
Acceleration Track	(Can be common for ABPS and OMS Tanks)
Support Equipment	GN_2 Support Equipment
	GHe Support Equipment
	LH_2 Support Equipment
	LN_2 Support Equipment
	Water Support Equipment
	Test Instrumentation
	Test Data Recording Equipment
	Test Fixtures
	Safety Equipment
	Acceleration Load Controls
	Test Article Transport/Handling Equipment
	NDE Support Equipment
Software	Program for Acceleration Load Schedule, Data-Reduction

TABLE 3.2-10. SUBSYSTEM SUPPORT EQUIPMENT/ SOFTWARE REQUIREMENTS (Sheet 3 of 7)

Item	Requirements
Slosh Rig Support Equipment	(Main LH_2 and LO_2 Tanks) Referee Fluid Support Equipment Test Instrumentation Test Data Recording Consoles Test Fixtures Test Article Transfer/Handling Equipment
Software	None
For Elemental Testing Support Equipment	(May be common for main LO_2 and OMS Tankage) GN_2 Support Equipment GHe Support Equipment (Small scale support rigs to be consistent with test facilities) LH_2 Support Equipment LO_2 Support Equipment LHe Support Equipment Test Instrumentation Data Recording Equipment Test Fixtures Safety Equipment NDE Support Equipment
Software	None

TABLE 3.2-10 SUBSYSTEM SUPPORT EQUIPMENT/
SOFTWARE REQUIREMENTS (Sheet 4 of 7)

Item	Requirements
Acceptance Test Stand	(May be common for main LH_2 and LO_2 Tanks)
Support Equipment	LN_2 Support Equipment GN_2 Pressurization Equipment GHe Support Equipment NDE Support Equipment Safety Equipment Test Data Recording Consoles Hydraulic Load Controls Test Instrumentation (T/C, Strain Gages, Accelerometers & Transducers Test Article Transport/Handling Equipment Test Article Transport Hardware (Protective) Test Fixtures (Separate for LH_2 and LO_2)
Software	Program for: Data Reduction

TABLE 3.2-10 SUBSYSTEM SUPPORT EQUIPMENT/
SOFTWARE REQUIREMENTS (Sheet 5 of 7)

Item	Requirements
Hydrostatic Test Facility	(Can be common for Main LH_2 and LO_2 tanks used for Structural qual.)
Support Equipment	Water Supply Water Purification Support Equipment Water Pressurization Equipment GN_2 Support Equipment GHe Support Equipment Test Instrumentation (T/C, Strain Gages, Accel. Trans) Load Control Equipment (Hydraulic, Servo Type) NDE Support Equipment Safety Equipment Test Fixtures, Test Stand Test Data Recording Consoles Test Article Transport/Handling Equipment
Software	Programs for: Data Reduction Mission Load Spectrum

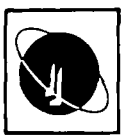

TABLE 3.2-10 SUBSYSTEM SUPPORT EQUIPMENT/
SOFTWARE REQUIREMENTS (Sheet 6 of 7)

Item	Requirements
Vacuum Chamber Facility	(Can be common for OMS, LH_2 and LO_2)
Support Equipment	LO_2, LH_2, LN_2, GN_2, GHe — Support Equipment NDE Support Equipment Temperature Conditioning Equipment Test Instrumentation Test Fixtures Heat Leak Measurement Devices (Vent Gas) Data Recording Consoles Test Articles Transport/Handling Equipment Safety Equipment Purge System (Vehicle Simulated)
Software	Program for: Data Reduction

TABLE 3.2-10 SUBSYSTEM SUPPORT EQUIPMENT/ SOFTWARE REQUIREMENTS (Sheet 7 of 7)

Item	Requirements
OMS Tank Testing Chamber (DVT)	
Support Equipment	GN_2, GHe, LN_2, LHe — Support Facility
	Safety Equipment
	NDE Support Equipment
	Test Instrumentation
	Test Data Recording Equipment
	Temperature Conditioning Equipment
	Test Fixtures
	Purge System
Software	Programs for: Data Reduction
Vibration Rig	(Can be common for OMS and ABPS tanks)
Support Equipment	Referee Fluid Support Equipment
	LN_2, LH_2, GHe — Support Equipment
	Test Instrumentation
	Test Data Recording Equipment
	Safety Equipment
	Test Article Handling/Transport Equipment
	Test Fixtures
	NDE Equipment
	Temperature Conditioning Equipment
Software	Programs for: Data Reduction
	Load Spectrum (Separate Programs)

TABLE 3.2-11 FACILITY REQUIREMENTS LIST (Sheet 1 of 2)

Title and Description	New	Exist.	Contr.	Gov.
Element Testing Rigs - (OMS LO_2 tank) multiple test apparatus which provides temperature exposure (LN_2/LO_2 to 300°F), vibration, loads and measures structural design indicators		X		
Element Testing Rigs - (OMS LH_2) similar to OMS LO_2 except (LHe/LH_2 to 300°F) temperature exposure		X		
Full Scale DVT Testing - (OMS LO_2 and LH_2) - vacuum chamber, cap. 10^{-6} torr +300°F to LN_2 temp, GN_2 purge - for performance evaluation of insulation - (25 ft high x 20 ft dia vacuum chamber) use of test fluids LN_2 &LHe		X		
Test Stands - Possible common usage for main LH_2 and LO_2 work area: 110 ft high x 24 ft dia.; insulated plastic shrouds for both tank configurations; static loading capability and pressurization capability hazardous test area design with remote control room. Hook Height: 120 ft	X		X	
Hydrostatic Test Facility - possible common usage for main LH_2 and LO_2 tanks; 100 ft long x 20 ft dia; inhibited water supply; hazardous test area design with remote control room; static load and pressurization capability	X		X	
Element Test Rigs - (for LO_2 tank testing) - multiple test apparatus which provides temperature exposure (LN_2 to 300°F); provides vibration, fatigue-type loads and measures structural design indicators		X	X	
Slosh Test Rig - for main LH_2 and LO_2 tanks; shaker system		X		
Hydrostatic Test Facility - common usage for OMS tank and ABPS tanks work area 20 ft long x 16 ft dia; inhibited water use; hazardous area design			X	

TABLE 3.2-11 FACILITY REQUIREMENTS LIST (Sheet 2 of 2)

Title and Description	New	Exist.	Contr.	Gov.
Vacuum Chamber - for OMS tank (LH_2 and LO_2) work area 25 ft high x 20 ft dia; 10 torr capability; LH_2, LN_2 capability; GN_2 purge system	X		X	
Acceleration Track Rig - May be common to ABPS tanks (perm & ferry) and OMS tanks (LH_2 and LO_2); provide g exposure	X		X	
Shaker System - (OMS tanks) - max. weight 20,000 lb		X		
Shaker System - (ABPS tanks) - max. weight 30,000 lb		X		
Fatigue Test Stand - may be common for OMS LO_2 and LH_2 tanks - thermal/pressure cycle capability using cryo fluids LH_2 or LN_2		X		

3.3 EXTERNAL LH_2 TANK

3.3.1 PRINCIPLE FEATURES AND DESIGN CHARACTERISTICS

The cryogenic propellant is contained within a 2219 aluminum semimonocoque pressure shell which has mechanized TIG weld joints. External S-II type foam insulation provides acceptable LH_2 heat leak/boiloff characteristics.

In addition, an ablative surface is placed external to the nose fairing and on other local areas where higher launch heating rates are expected. The nose fairing main structural elements are sheets and stringers. The electronics contained within the tank nose fairing consists of standard circuitry and components which are certified as part of the orbiter avionics development test program. The command receivers and decoders are basically off-the-shelf units.

Tank supports are tubular aluminum members attached to the forward dome of the cylindrical section to laterally restrain it, two aft aluminum struts that act as stabilizing members, and an aft shear connection to resist drag and vertical loads.

The tanks are attached to the orbiter by several couplings: two electrical, three fluid and three structural. All of these disengage as planned for successful tank ejection. Electrical coupling is through bayonette type disconnects and structural coupling is through "Marman" type clamps. The force required for tank ejection is provided by two pyro actuators.

Tank separation is nominally accomplished during the coast phase of orbiter flight (orbiter burnout) at which time, following tank depressurization, all the structural, propellant, and electrical connections are separated.

The tank electrical/electronics package consists of the following:

- The jettison circuit operates the fore and aft jettison thrusters and releases the Marman clamps which secure the three tank-mounting struts to the orbiter
- The de-orbit circuit opens a port in the tank fairing to expose the SRM nozzle and initiates de-orbit SRM firing via an rf link
- Three batteries provide power for the jettison circuits. An interlock circuit is provided to arm and fire each initiator circuit

The baseline external tank separation design is established from design reference mission requirements, defining nominal tank separation at dynamic pressures of less than 1 lb/ft^2. Mission abort requirements, for orbiter return to the launch site, have identified abort-mode tank separations at dynamic pressures of 10-50 lb/ft^2. The impact of the abort mission requirements on the baseline design is analyzed and evaluated during the engineering development phase.

Tank disposal, during reentry is primarily achieved by oxidation. The external tanks are fabricated of aluminum to encourage tank breakup at an altitude of about 300,000 ft to facilitate burnup of the tank fragments. Preliminary analyses indicate that most tank fragments burnup during entry. Subsequent analyses establish the size and dispersion of surviving pieces, if any.

3.3.2 ENGINEERING ISSUES ASSOCIATED WITH EXTERNAL TANKS

Because the H-33 LH_2 tanks are externally mounted, floating, disposable tanks, designed for a single mission life, and because they incorporate existing Saturn S-II type NOPCO external foam insulation, a number of engineering development issues are dismissed with a fraction of the effort required to analyze, design, and development test reusable, integral, internal LH_2 tanks. For example:

- Fracture control effort is reduced
- Tank testing separated from vehicle structural testing reduces risk and simplifies testing

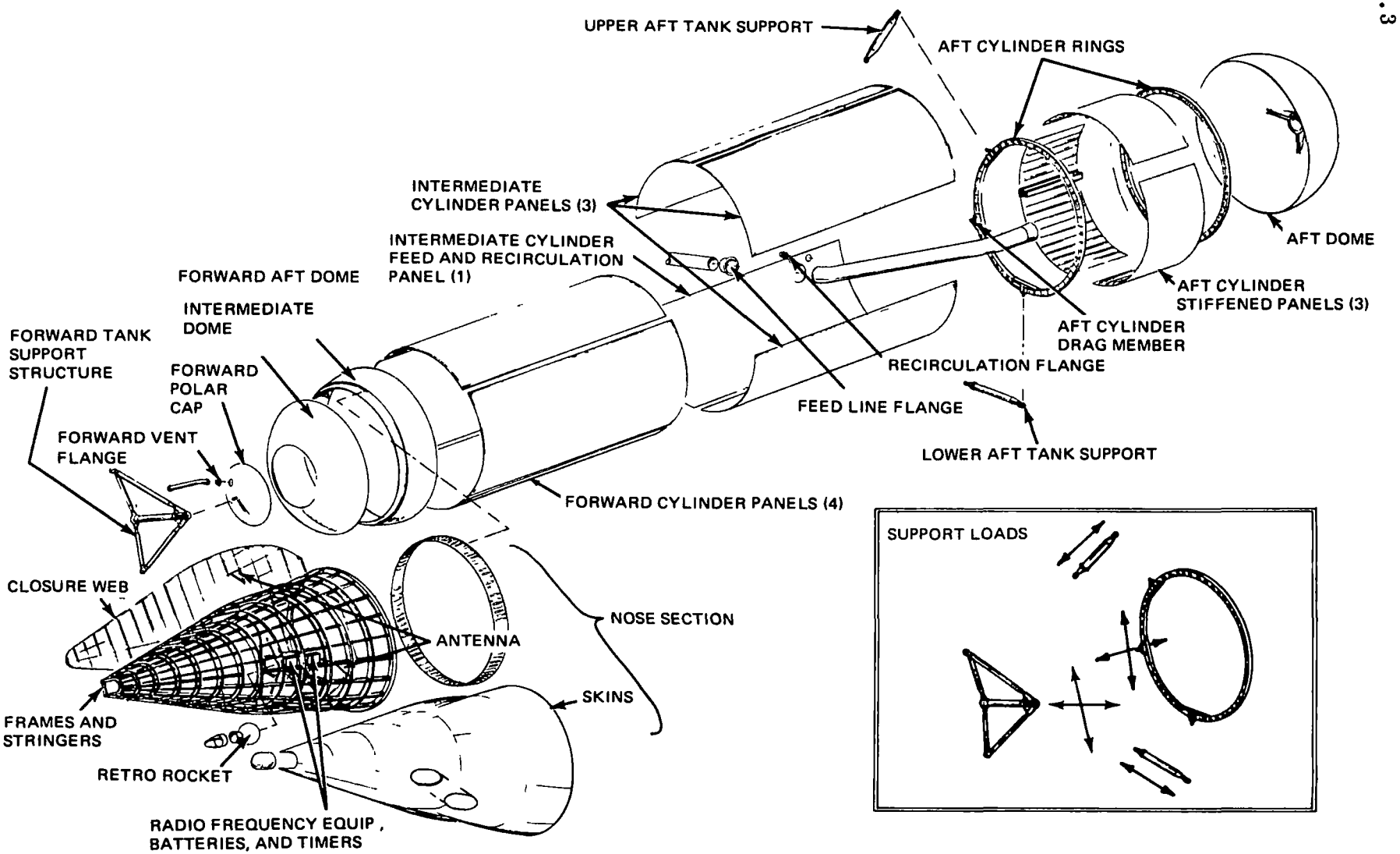

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Fig. 3.3-1 Exploded View of Tank

- Tank cycle life certification testing is reduced
- Proof-testing is simplified by using a non-hazardous gas such as GN_2, rather than LH_2
- Insulation testing is reduced drastically - relying on certification by similarity to S-II
- Development of new insulation repair techniques is eliminated - relying on qualified S-II procedures

A number of other issues are raised with respect to the use of external tanks which are subjected to air loads, separated and ejected from the orbiter (without recontacting the orbiter) and finally consumed as they reenter the atmosphere. For example:

- Dynamic effects of external tanks: wind tunnel test data and structural and propulsion system component test data provides inputs to the structural/propulsion math model to verify the absence of a dynamic problem. Full-scale modal vibration surveys on an unfueled orbiter and on the fueled mated orbiter/booster configuration verifies the analytical model
- Propulsion disconnects: Component tests on structurally loaded (statically and dynamically) disconnects verify proper separation and the absence of GH_2 leaks and detrimental frost buildups
- Effects of ground hold (sun, wind, sea-air, humidity and rain) and launch and boost environments (temperature, vibration, acceleration and pressure): Tests on representative panels of insulation plus ablator certify the adequacy of the composite. Insulation-only tests are reduced based on certification by similarity to S-II insulation
- Tank venting in orbit: Normal tank venting during fill, ground hold and ascent are demonstrated on the propulsion test article. Venting of the tank in orbit is certified by analysis plus high speed photography of small tank sample tests in a high vacuum

- Tank separation and ejection without recontact: Each component associated with the separation is qualified at the component level. Analytical techniques are used to predict maximum dispersions which affect tank separation. An all-up test using a suspended tank certifies that with these maximum adverse dispersions, there is no recontact

- Tank consumability and dispersions during reentry: Element testing certifies oxidation rates on composite or difficult-to-analyze geometrical shapes; certification of complete consumability is by analysis; certification of reentry trajectory dispersions is by analysis

- Tank depressurization, separation and ejection during abort modes: Certification of the basic hardware elements is accomplished at the component level, superimposing static loads for dynamic loads; certification of separation and ejection under air loads is accomplished by analysis, and a series of captured trajectory tests and free-fall tests in a wind tunnel

3.3.3 CERTIFICATION TEST PROGRAM

This subsection establishes the test program and development logic for the tank. The external LH_2 tank assembly is separated into three subassembly areas as follows:

- Pressure vessel which includes structural elements, tank insulations, and propulsion system elements

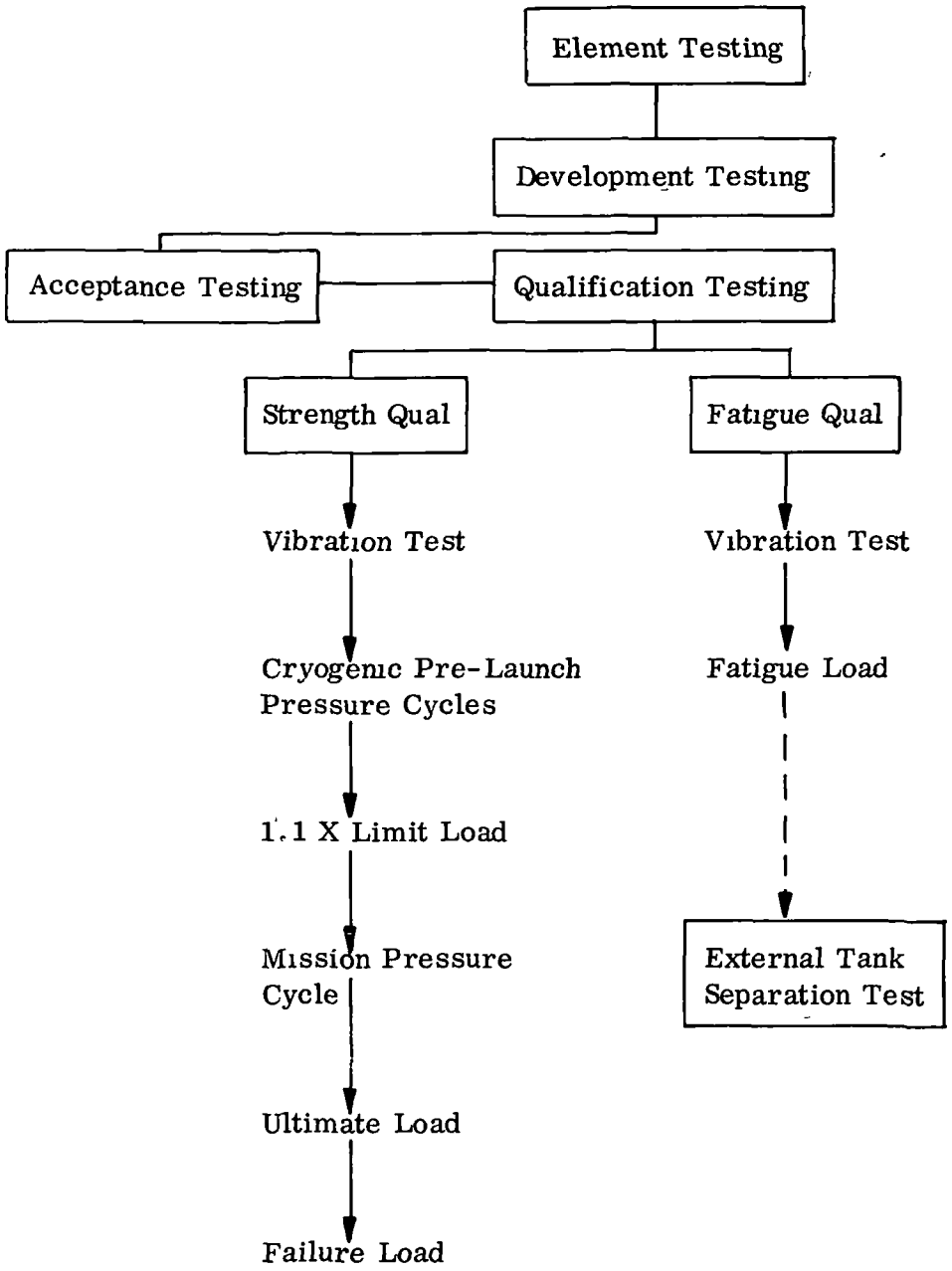
- Nose fairing assembly which includes solid rocket motor (SRM), electronics, orbiter/tank interface seal, structural elements, and ablator

- Pyrotechnic assembly which includes support struts, separation clamps and pyro actuators

The test program for each subassembly is composed of four phases: element testing, development testing, acceptance testing and flight qualification demonstration.

3.3.3.1 Propellant Pressure Vessel

The test flow diagram is shown below:



The tank used in the fatigue qualification demonstration is used for the external tank separation test.

3.3.3.1.1 Element Testing

This program provides all required design data on tank materials. Typical examples are:

- Spray-on ablator recession rates
- Fracture mechanics data (reduced for single mission tanks)
- Thermal conductivity of foam insulation
- Effect of environmental exposure on foam performance
- Effect due to exothermal reaction of foam insulation installation

Since the baseline NOPCO foam insulation is the same as that used on the Saturn S-II, development testing of the foam is significantly reduced.

3.3.3.1.2 Development Testing

During development, a tank shell test section is configured to evaluate the insulation for environmental effects (humidity, salt air, altitude, rain, vibration induced removal of ice, and thermal strain effect). LHe is used as the test fluid.

The liquid hydrogen interface connections between the external tank and orbiter represent potential GH_2 leak sources and potential heat leaks. GHe purge chambers enclose the joints to prevent frost formation and hazardous GH_2 buildup, and to lower the heat leak into the hydrogen. By subjecting the interface connectors including their simulated purge system to cryogenic flow and pressure tests, a verification of design and analysis is made. The tests provide data on GH_2 leakage and on heat leak, frost accumulation and mechanical separation forces. Of particular interest is the prevention of fluid leakage in and around the interface connection, with structural and thermal deflections and under cryogenic fluid pressure. Sealing qualities under these conditions, are evaluated for possible degradation.

During a launch-hold period, ice accumulation may result on the LH_2 tank/orbiter structural, fluid and electrical couplings. An analysis/test program determines the quantity of ice remaining, after the end of orbiter injection burn, in areas that might impair the separation of tank from orbiter.

Propellant slosh tests and outflow tests are conducted in reduced scale transparent tank models to evaluate vortex effects and to establish requirements for anti-vortex baffles and propellant feedline outflow configurations.

3.3.3.1.3 Acceptance Testing

To assure that all tanks are fabricated with high quality standards comparable to the tanks which successfully pass the qualification tests, all tanks are subjected to acceptance testing, at a proof pressure of 1.05 times the maximum expected operating pressure (MEOP) at cryogenic temperatures. The test gas is GN_2 or other non-hazardous gas.

The tank is proof tested prior to installation of the foam insulation because of its temperature sensitivity. After NDE procedures, the foam insulation is installed.

3.3.3.1.4 Qualification Testing

Ability to ratio tank design stress levels (due to external loads and pressure conditions) from cryogenic to ambient temperatures allows static tests to be completed in a hydrostatic pressure facility. Dynamic pressure effects are applied to the tank using load distribution devices. The nominal life-cycle of an external hydrogen tank contains one acceptance test pressurization, some low pressurization cycles for transportation and storage, the pre-launch pressure cycle during loading of LH_2 and the pressurization which results from ascent accelerations and the in-flight pressure system.

Since tanks may experience pre-launch aborts and still be expected to successfully survive, the qual test pressure cycle includes the normal life cycle pressure history plus additional fill cycles to preclude the possibility of tank deterioration.

Liquid H_2 fill demonstrations are part of the program; recycling the propellant load to demonstrate ground abort capability is also included. Vibration testing is performed using a fluid mass simulator and the flight tank support struts. Both a filled and an empty tank are tested.

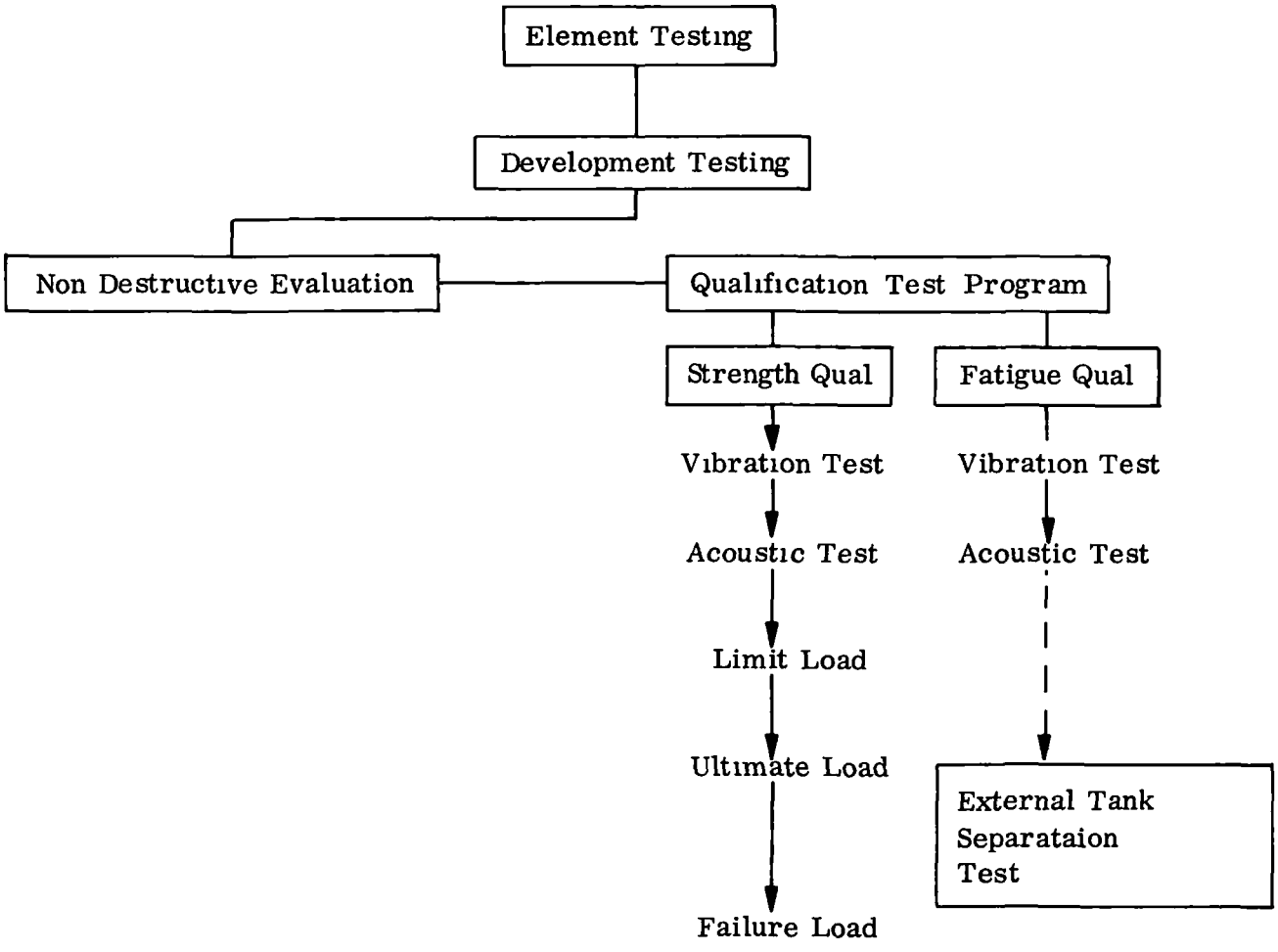
The following features of the LH_2 disconnect are verified by testing:

- Low external leakage
- Ability to prevent liquid air or ice formation
- Ability to minimize heat leak
- Ability to withstand vibration and thermal environment
- Disconnect under the full array of mechanical alignments

The test article is a flight weight disconnect assembly, consisting of the main line disconnect, the recirculation line disconnect, the vent/autogenous pressurization line disconnect and their purge chambers. The tank half of the purge chambers is simulated by a curved plate.

3.3.3.2 Nose Fairing Assembly

The test flow diagram pertinent to the nose fairing assembly is presented below:



Components included within the nose assembly undergo test programs designed to establish flight integrity on the component level. Particular examples are the solid rocket motor and electronics.

3.3.3.2.1 Element Testing

This phase of the program provides all material data pertinent to the design criteria. Included are:

- Ablator heating characteristics
- Seal characteristics

- Thermal stresses due to temperature transients
- Material strength characteristics
- Environmental effects on ablator characteristics

3.3.3.2.2 Development Testing

A test is run to substantiate the structural elements of the nose cone. Test data for shear lag/indeterminate load distribution is obtained and compared with analytic results from the comap-astral computer model.

A skin/stringer/frame attachment test establishes weld bond or rivet bond configuration. Strength characteristics of ablator adhesion are demonstrated by testing combinations of skin gages/ablator thicknesses under the design environment. This data is also used to optimize the skin in terms of buckling criteria.

The orbiter tank seal effectiveness is verified by analysis and scale model wind tunnel tests. Seal integrity is verified by tests which provide the ascent heating rates and vibration environment. Air and inertia loads are simulated statically.

The solid rocket motor (SRM) is of the Aerojet SVM (space vehicle motors) family and requires only minor nozzle and propellant grain modifications prior to delta-qualification. The motor case, igniter, chamber, and mounting flange are identical to an existing motor. In addition, the nozzle materials and general construction are the same as the existing SVM motors.

The SRM development program consists of vibration and thermal vacuum preconditioning followed by static firing tests on 10 development motors. An additional 10 motors are required for delta-qualification tests. Four motors are fired at each of the temperature extremes and two at nominal temperature. All firing tests are in a six component thrust stand in a vacuum facility.

Normal avionics development test procedures and techniques are applied to verify that each electronic component/assembly meets its performance requirements. These include antenna coverage pattern measurements, standard EMI tests, and demonstration of the orbiter/tank command and status monitoring links.

3.3.3.2.3 Qualification Testing

Each component undergoes a separate qualification test program. Particular attention is given to vibration and acoustic testing of the assembly. Structural integrity is demonstrated by application of static and fatigue loads.

Since the SRM is being adapted from an existing design, the major effort is performed in the development period and, therefore, only a delta qualification program is required.

3.3.3.3 Pyrotechnic Actuation

Commencing with contractor requirements (such as force, stroke, effective tank mass, onset rate, etc.) the seller activity proceeds as follows:

- DFT - Propellant Charge Determination: A propellant can, with booster and sustainer charges, is rough sized analytically, fabricated and used in conjunction with a boiler plate actuator fabricated of steel. The boiler plate model is designed to the pressure/area characteristics to satisfy requirements. Structural stiffness is simulated during testing. The test rig is a weight (tank effective mass) suspended from a cable sufficiently long to provide satisfactory test results over the first 12 to 20 inches of travel. A total of 70 firings are made: 30 ambient, 20 hot, and 20 cold. Only slight adjustments are made in the propellant grain geometry. Ignition modes are studied in a series of single, double, and triple igniter firings

  - Coating Study - Since the baseline design is an all-aluminum constructured actuator, a second boiler plate model, with a removable inner sleeve is used to evaluate aluminum alloys and surface coatings with respect to the propellant charge previously determined. A total of 50 firings at high temperature are anticipated

  - Prototype Aluminum Actuator - A prototype actuator is designed on the basis of previous test results, and fabricated. Propellant characteristics are combined with an all-aluminum actuator for 33 firings: 10 ambient, 10 hot, 10 cold, and 3 hot with 125% propellant charge for structural integrity purposes

- "Lock Shut" - Using the prototype design, three hot firing tests are run with the actuator inhibited against stroking. These tests are performed to demonstrate that an inadvertent firing produces no shrapnel nor causes any structural damage to the tank

- Burst Test - Two prototype designs are pressurized hydraulically to demonstrate proof load and burst load structural characteristics

- Statistical Factorial Test - This entails a quantitative determination of performance level variations (within spec) due to anticipated production and assembly line variables especially in the area of propellant grain characteristics. A total of 32 firings are anticipated: 16 hot and 16 cold

- Accelerated storage life test - The propellant can is subjected to accelerated life and approximately 20 firings are made to determine storage life effects on performance level

- Closed bomb tests - The closed bomb test is conducted in a confined volume. Pressure levels are recorded to establish the baseline output that serves as a measured reference criterion for future production runs and their lot acceptance tests. A total of 40 shots are required; 20 hot and 20 cold

- Overstress/Margin test - In the prediction of failure modes it is necessary to investigate possible fabrication and assembly defects (high humidity, propellant contamination, etc.) and their effects on performance. Approximately 20 firings are anticipated

- DVT - This is essentially a pre-qual test which involves a limited number (approximately 21) of test units subjected to only the more severe test environments. These tests are run and any failures are resolved before committing the much larger qual lot to test. The anticipated test environments are:

  - Humidity
  - Shock and vibration
  - Thermal/vacuum
  - Thermal cycling

- Qual - All required environments are included. Approximately 150 firings are anticipated

3.3.3.4 External Tank Separation Demonstration

Beyond the component and subassembly certification level tests, an all-up tank separation test is conducted to certify all the significant interfaces. This combined systems test includes the following:

- Demonstrate satisfactory release of all interfaces with no recontact
- Demonstrate that the translational and rotational rates imparted to the tank are within acceptable limits
- Demonstrate no fragmentation (shrapnel, ablator, etc.)

Tank separation studies are performed using an all-digital six-degree-of-freedom program incorporating detailed math models of the forces and moments acting prior to and during the separation sequence. These math models are established from wind tunnel test data on orbiter models with the tanks attached under various dynamic pressures and angle-of-attack conditions. Propulsion forces due to venting and depressurization of the tanks prior to separation, and separation forces due to linkage and jettison impulses also are included in the math model. The results are used to establish the tank separation design requirements and to verify the tank separation clearances for nominal and abort mission modes.

The dynamics of free body tank motion are duplicated by suspending a horizontal tank from a long cable whose upper end is movable and capable of remaining over the tank center of gravity. The cable support permits three-rotational-degrees-of-freedom for the tank. The upper cable point has two-translational-degrees-of-freedom in the horizontal plane. Immediately after firing the separation actuators, the upper cable point is moved at the anticipated velocity of the tank center of mass. When a sufficient lateral separation distance is achieved, the de-orbit rocket system is activated to demonstrate SRM door opening and electrical continuity. No SRM is present for this test. Tank velocities are sensed and used to predict subsequent tank motion.

This test assures that tank separation occurs without recontact with the orbiter, that all orbiter/tank couplings have released, that pyro actuators have functioned as expected and that electrical devices are capable of functioning after separation.

3.3.3.5 External Tank Separation During Abort Modes

To certify the separation and ejection of the external LH_2 tanks during high g abort mode conditions, a series of wind tunnel tests are conducted in the same manner as is done on stores and drop tanks on the F-111B and the F-14 aircraft.

A matrix of tests are conducted as early in the program as possible, but only after the tank location has been narrowed down by preliminary analysis. These early matrix tests provide experimental data for further refined analytical separation studies using three- and six-degree-of-freedom programs. This is followed by captured trajectory tests of critical areas in the separation envelope (as defined by analysis).

The early data is taken in matrix form, i.e., the geometric relationship between orbiter and tank is systematically varied in x, y, z displacement, tank attitude with respect to orbiter, and orbiter tank attitude with respect to the free stream velocity vector. In addition, Mach number and Reynolds number are also varied: Mach number to cover the abort and nominal separation range and Reynolds number to determine the effects of non-full-scale simulation on the interference aerodynamic characteristics. Six-degree-of-freedom force and moment measurements of the orbiter and the tanks are made independently while affected by the interference flow field.

The captured trajectory tests verify critical safe separation envelope areas. Captured trajectory runs require the independent six component measurement of forces and moments on both orbiter and tanks. In addition, the information is fed to a computer which calculates the relative location of the tank and orbiter models for the next test run. This

process continues until either impact or assurance of a safe separation exists over a time-scaled separation trajectory. Several tunnels exist which can do this work over different Mach number ranges:

CAL	8 ft transonic
AEDC	40 in. hypersonic
LTV	4 ft transonic/supersonic
Convair	4 ft subsonic/transonic/supersonic

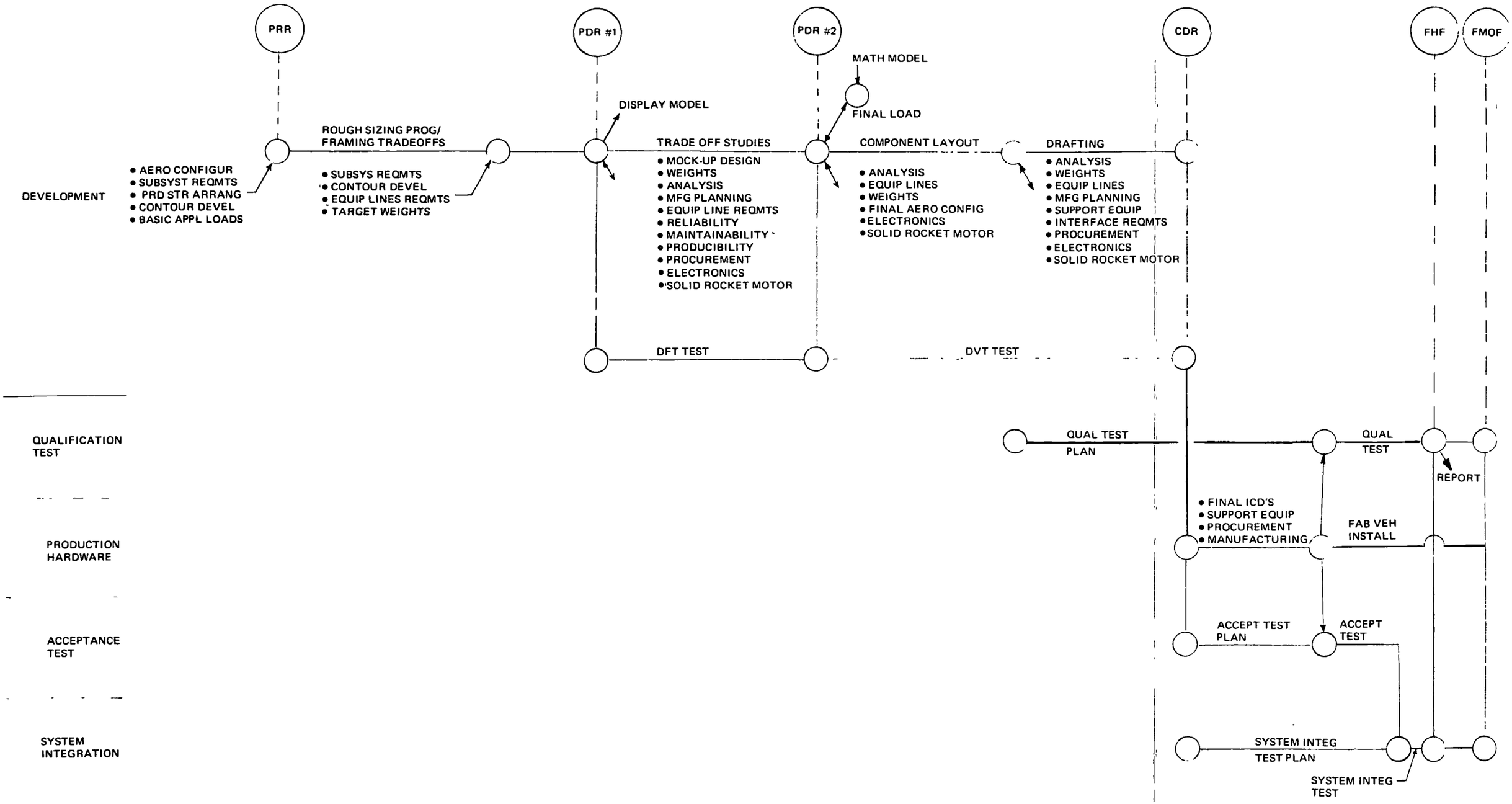


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Fig. 3.3-2 External Tanks Logic Network

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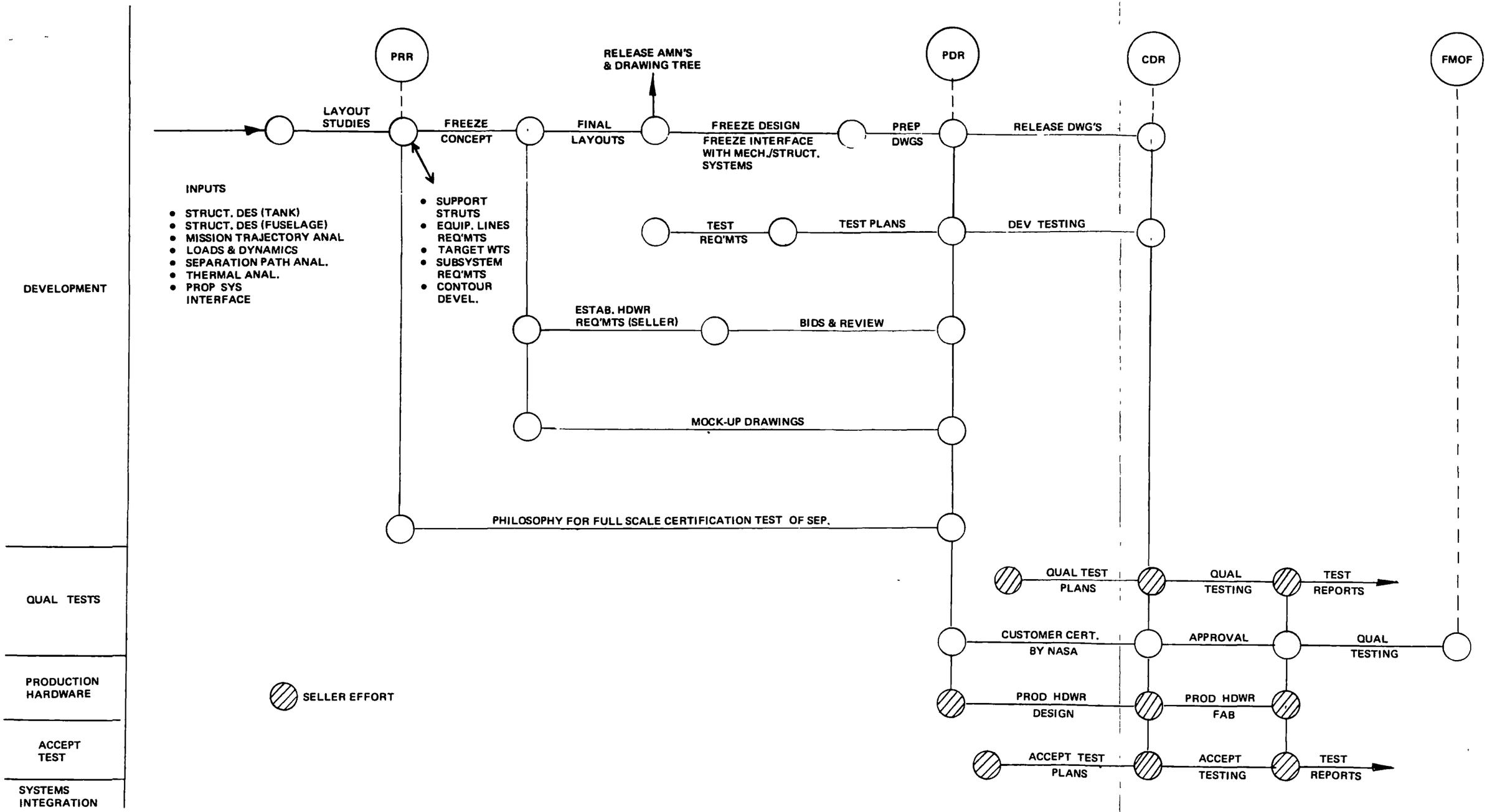

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Fig. 3.3-3 External Tanks Separation Logic Network

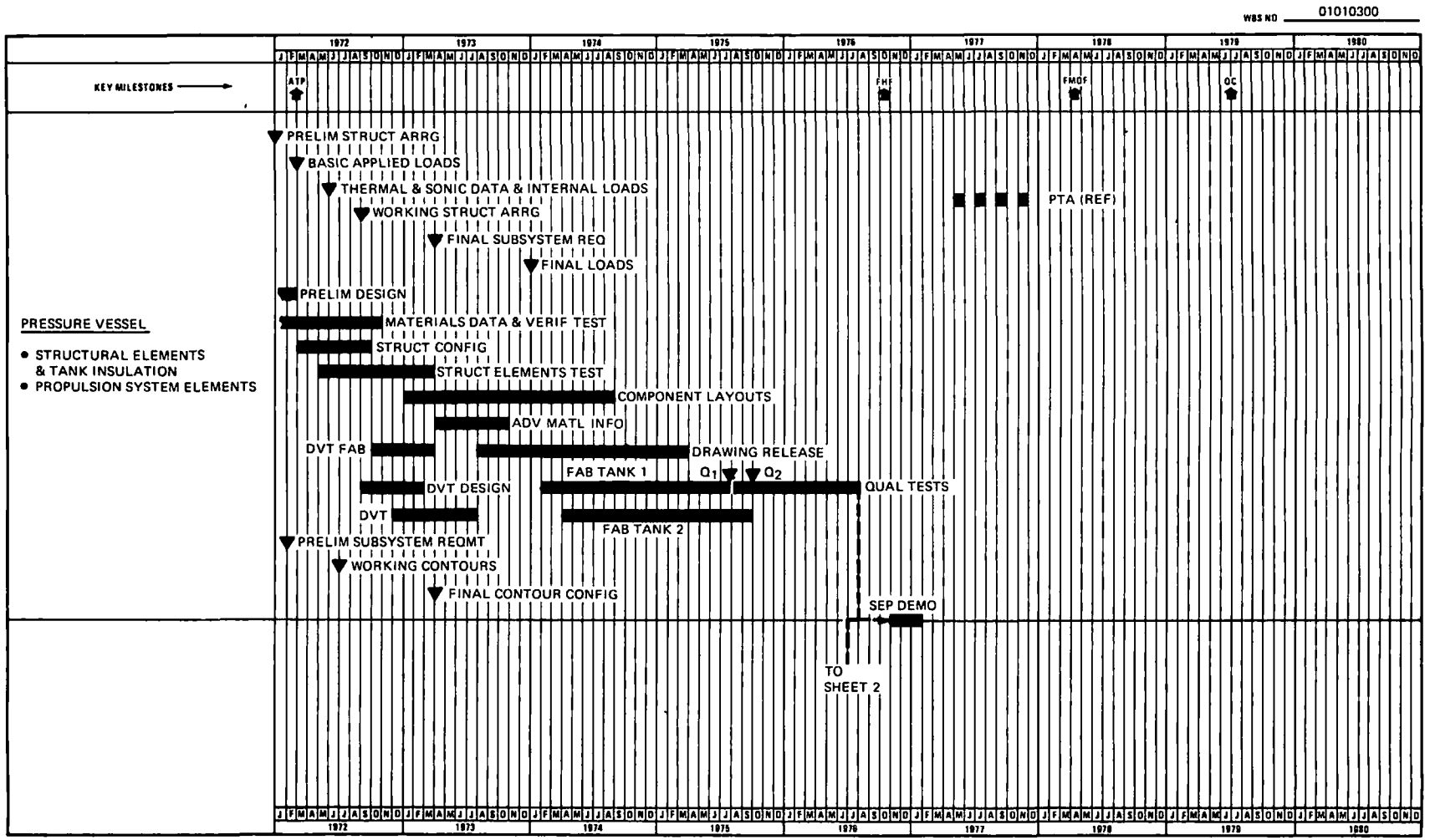

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Fig. 3.3-4 External Tanks Schedule (Sheet 1 of 2)

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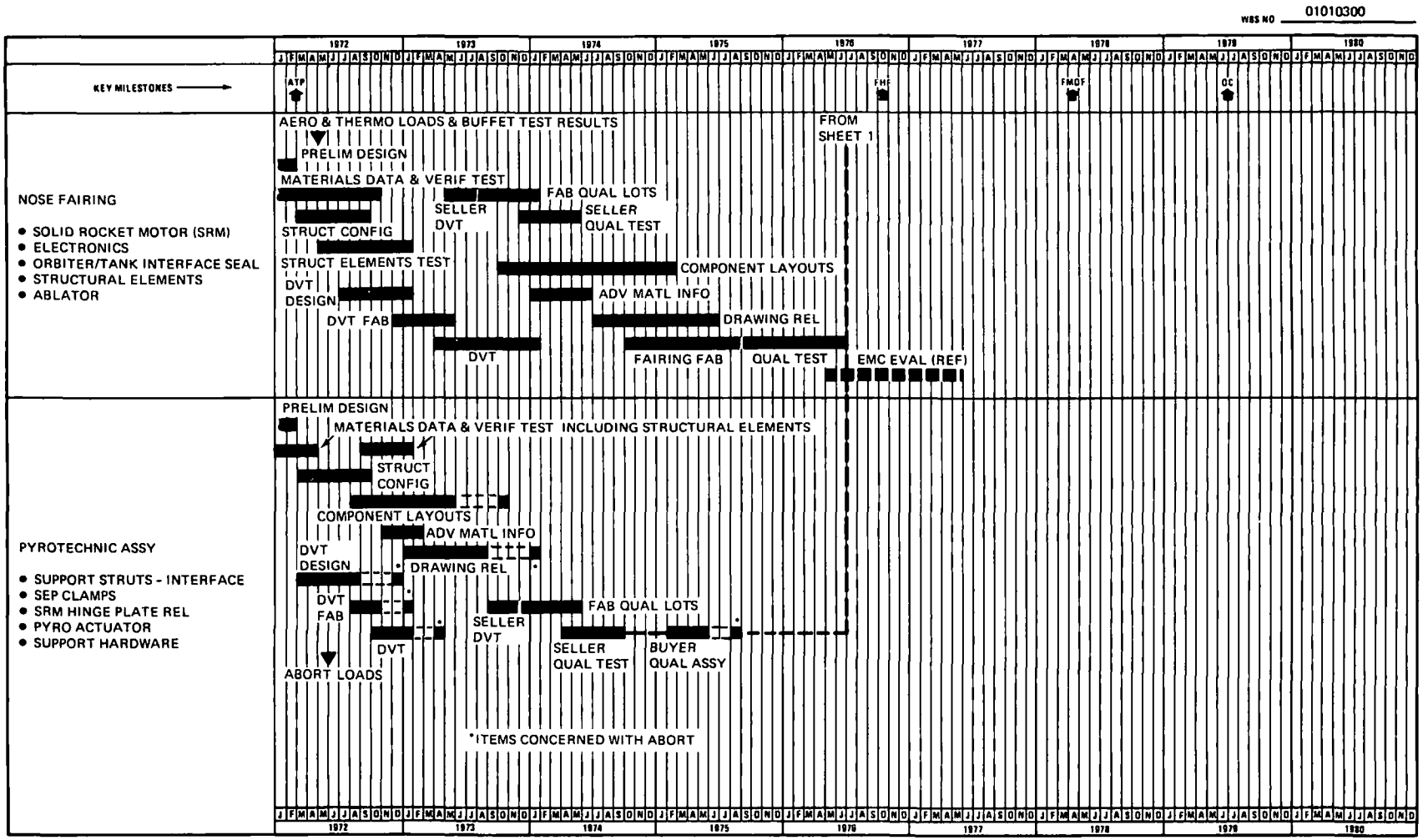

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Fig. 3.3-4 External Tanks Schedule (Sheet 2 of 2)

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TABLE 3.3-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 1 of 5)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation/Model	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
Thermodynamics											
1. Frost/Buildup-Evaluation on Model	X				X						
2. Thermal conductivity of foam	X		X								
3. Foam/Ablator Aero Heating	X		X		X						
4. Ablator/Foam/Aluminum - Thermal pressure cycling on model	X	X			X						
5. Aero heating of											
(a) Strut Ablator	X				X	X	X				
(b) Fluid/Electrical Interface Ablator	X				X	X	X				
(c) Nose Cone/SRM Door Ablators	X				X	X	X				
6. Nose Fairing/Orbiter Seal Evaluation	X				X						
Vehicle Propulsion System											
1. Propellant/Pressurization Line Joint Evaluation	X				X	X	X	X			
2. Propellant Slosh and Outflow Characteristics	X	X			X						
3. Autogenous Pressurization										X	
4. External Line Heating - Propellant Flow Evaluation					X		X				
5. Tank venting evaluation	X	X			X	X	X			X	X

TABLE 3.3-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 2 of 5)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation/Model	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
Tank Wall Integrity											
1. Stress corrosion in LH_2 environment					X						
2. Fatigue flaw growth		X			X						
3. Fatigue flaw growth on tank sections/ model	X	X			X						
4. Leakage evaluation on tank model	X	X			X						
5. NDE methods on tank model		X			X						
Structural Integrity											
1. Combined behavior of ablator/foam/ tank panel											
(a) Buckling behavior					X		X				
(b) Thermal stress due to foam installation and repair					X		X				
(c) Thermal Conductivity					X		X				
2. Nose Ablator/aluminum buckling criteria					X						
3. Skin, stringer, frame joint investigation					X						
4. Vibration Tests											
(a) Panel structural characteristics					X						
(b) Acoustic loading of nose fairing					X	X	X				
(c) Ground vibration survey	X					X					X

TABLE 3.3-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 3 of 5)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation/Model	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
5. Major components											
(a) Fwd nose dome with small cylindrical segment						X	X				
(b) Nose fairing						X	X				
(c) Aft framed bay and dome						X	X				
(d) All external support members						X	X				
6. Tank											
(a) Acceptance								X			
(b) Thermal gradients and pressure leak						X		X			
(c) Low frequency vibration	X					X		X			
(d) Multiple pressurization cycles	X					X		X			
(e) 1.1 times limit load application	X					X		X			
(f) Ultimate pressure	X					X		X			
(g) Pressure test to failure	X					X		X			
(h) Fatigue life	X					X		X			

TABLE 3.3-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 4 of 5)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation/Model	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
Nose-Fairing/Orbiter Seal Integrity	X				X	X	X				
Electrical/Electronic Systems											
1. EMC evaluation						X					X
2. Antenna system spatial coverage	X	X			X	X	X				
3. Battery power supply						X	X				
4. Circuit interlock sequencing						X		X			
5. Remote multiplexer signal transer						X		X			
6. Compatability of antennas, receivers and couplings						X		X			
7. Digital signal transfer						X		X			X
Impulse Devices											
1. Pyrotechnic charges					X	X	X				
2. De-orbit solid rocket motor					X	X	X				
3. De-orbit SRM/nose fairing interaction					X			X			
Separation System											
1. Pyrotechnic actuators						X	X				
2. Structural disconnects						X	X				
3. Fluid disconnects					X	X	X				
4. Electrical disconnects						X	X				
5. Orbiter pierce point door closure						X	X				
6. External tank separation test	X					X		X			

TABLE 3.3-1 SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 5 of 5)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation/Model	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
Tank Disposal After Entry											
1. Tank break up in atmosphere	X										
2. Dispersion of tanks and pieces	X	X									
Wind Tunnel Tests of Tank/Orbiter/Booster Ascent Config											
1. Buffet on elastic model		X			X						
2. Flutter on elastic model		X			X						
3. Slosh on elastic model		X			X						
4. Configuration controllability on elastic and rigid models		X			X						
5. Air pressure fluctuation at tank/orbiter region - on rigid model		X			X						
Pogo Susceptability											
Tests on propulsion components	X	X			X		X				
Tests on PTA	X				X					X	

TABLE 3.3-2 MAJOR COMPONENT LIST

Comp. No.	Component Description	Qty/ Vehicle	Weight Each, Lb	Size Each, Ft
1	Nose Fairing Assembly	2	1356	23
2	Fwd. Dome	2	375	
3	Aft. Stiffened Section and Dome	2	1680	
4	Center Cylindrical Tank Section	2	1200	
5	Fwd. Truss Assembly	2	88	
6	Aft. Attachment Hardware	2	33	
7	Solid Rocket Motor	2	373	
8	Propulsion System Hardware	2	326	
9	Separation System Hardware	2	77	
10	Electrical System Hardware	2	88	
11	Electronic System Hardware	2	39	

TABLE 3.3-3 REQUIRED EQUIVALENT UNITS

Hardware Description	Required Equiv. Units
Flight Hardware Per Vehicle	445/4LH 445/4RH
Component Devel & Qual Test (See Note)	1.0 (Qual) 0.5 (Slosh) 0.5 (Separation effects) 0.2 (DVT Subscale) 0.2 (Element)
Integration Tests	
• Full Mission Simulation Laboratory	None
• Integrated Avionics Test Laboratory	
• Flight Controls Hydraulic Test Laboratory	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	None
Test Articles	
• Propulsion Test Article (PTA)	(2)*
• Structural Test Article	None
Spares For Flight Test Program	1 Spare
Spares For 445 Flights	12

NOTE: 2 Separate Scale Models (DVT)
2 Pressure Vessels (Qual)
2 Nose Fairings (Qual)
1 Fwd Dome & Cylindrical Section (Qual)
1 Aft Stiffened Cylindrical Section and Dome (Qual)
1 Set of Attachment Struts (Qual)
1 Set of Separation Hardware (Qual)

*One Heavyweight and One Flightweight

TABLE 3.3-4 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS (Sheet 1 of 7)

Item	Requirements	
LH_2 Section Test (DVT)		
Support Equipment	GN_2 Support Equipment	
	GHe Support Equipment	
	LHe Support Equipment	
	LN_2 Support Equipment	
	NDE Support Equipment	
	Test Instrumentation	
	Test Data Recording Equipment	
	Test Fixtures	
Element Testing		
Support Equipment	LH_2 Support Equipment	Small scale rigs to be consistant with test facilities
	LO_2 Support Equipment	
	LN_2 Support Equipment	
	GHe, GN_2 Support Equipment	
	Test Instrumentation	
	NDE Support Equipment	
	Test Fixtures	
	Safety Equipment	
	Data Recording Equipment	

TABLE 3.3-4 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS (Sheet 2 of 7)

Item	Requirements
Vehicle Propulsion System Testing	
Support Equipment	Includes small scale rigs as well as PTA rig
	Support Stands (Hor. & Vert. Erect.)
	Access Stands
	Slings, Dollies, Jacks
	Component Support Fixture (Install)
	Component Protective Devices
	Tools and Fixtures for Install
	Rigging Devices
	GN_2 Support Equipment
	GHe Support Equipment
	LH_2 Support Equipment
	LO_2 Support Equipment
	LN_2 Support Equipment
	Safety Equipment
	NDE Equipment
	Test Instrumentation and Recording Equipment
	Test Fixtures
	Test Article Handling/Transport Equipment

TABLE 3.3-4 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS (Sheet 3 of 7)

Item	Requirements
Structural Integrity Testing (Hydrostatic Facility for Pressure Vessel)	
Support Equipment	Water Supply and Purification Support Equipment Water Pressurization Equipment GN_2 and GHe Support Equipment Test Instrumentation and Recorders Load Control Equipment NDE Support Equipment Test Fixtures, Test Stands Test Article Transport/Handling Equipment
Acceptance Test Stand	
Support Equipment	LN_2 Support Equipment GN_2 Pressurization Equipment GHe Support Equipment NDE Support Equipment Safety Equipment Test Data Recording Consoles Hydraulic Load Controls Test Instrumentation (T/C, Strain Gages, Accelerometers, Transducers) Test Article Transport/Handling Equipment Test Article Transport Hardware (protective) Test Fixtures (Separate for LH_2 & LO_2

TABLE 3.3-4 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS (Sheet 4 of 7)

Item	Requirements
Vibration Test	
Support Equipment	For LH_2 Tank
	Fluid Support Equipment
	LN_2 Support Equipment
	GN_2 Support Equipment
	GHe Support Equipment
	Safety Equipment
	NDE Support Equipment
	Test Instrumentation
	Test Data Recording Consoles
	Test Fixtures
	Test Article Transfer/Handling Equipment
	Temperature Conditioning Rig
Nose Fairing Assembly Qual Testing	
Support Equipment	Test Instrumentation and Recording Equipment
	Load Application Devices
	NDE Equipment
	Safety Equipment
	Test Fixtures
	Test Article Transport/Handling Equipment

TABLE 3.3-4 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS (Sheet 5 of 7)

Item	Requirements
Fill Test of LH_2 Tank	
Support Equipment	Test Instrumentation
	Safety Equipment
	Test Fixtures
	Test Data Recording Consoles
	NDE Support Equipment
	GN_2 Support Equipment
	GHe Support Equipment
	LH_2 Support Equipment
	LN_2 Support Equipment
	Vent Gas Measurement Device (Heat Leak)
Separation Test of LH_2 Tank	
Support Equipment	Test Fixtures
	Test Instrumentation
	Safety Equipment
	Test Article Handling Equipment
	Pyro - Actuation Device
	Pressurized Air Release Device
	Slings
	Access Stands

TABLE 3.3-4 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS (Sheet 6 of 7)

Item	Requirements
Aero Heating Tests	
Support Equipment	Test Instrumentation Data Recorders Test Fixtures
Slosh Rig Test for (Main LH_2 Tank)	
Support Equipment	Fluid Mass Representation Support Equipment Test Instrumentation Test Data Recording Consoles Test Fixtures Test Article Transfer/Handling Equipment
Structural Integrity Testing (DVT)	
Support Equipment	Test Fixtures Test Instrumentation Data Recorders Safety Equipment LN_2 Support Equipment LHe Support Equipment LO_2 Support Equipment LH_2 Support Equipment (Small Scale Consistant with Test Facility) Hydraulic Loading Devices Heating Devices (Lamps)

TABLE 3.3-4 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS (Sheet 7 of 7)

Item	Requirements
Hydrogen Line Disconnect Qual Testing	
Support Equipment	LH_2 Support Equipment GN_2 Support Equipment GHe Support Equipment LN_2 Support Equipment Heating Devices (Lamps) Safety Equipment NDE Equipment Special Low-Temperature Sensors Test Instrumentation and Recorders Documentation Cameras Test Fixtures

TABLE 3.3-5 FACILITY REQUIREMENTS LIST (Sheet 1 of 2)

Title and Description	New	Exist.	Contr.	Gov.
Slosh Rig Area - Evaluate dynamic characteristics of tank		X		
Acoustic Test Facility - DVT testing of sections of nose fairing assembly.		X		
Vibration Test Area - DVT testing of critical sections of nose fairing assembly		X		
Vibration Test Area - Qual testing of pressure vessel (electromechanical shakers)		X		
Hydrostatic Test Facility - Qual testing of pressure (100 x 20 ft dia)		X		
Acceptance Facility - Enclosed area to perform acceptance procedure on LH_2 Tanks		X		
Nose Fairing Qual Testing Area - Area in which to apply mission loading onto test article		X		
For Element Testing Rigs - Multiple test apparatus which provides temperature exposure (LH_2/LHe to +300°F), vibration, loads and measures design indicators		X		
Environmental Test Chamber - Altitude chamber which provides environmental effects (temperature, boost vibration, rain, salt air) on section of LH_2 tank		X		
Arc-Jet Facility - Provides aero heating input onto sections of tankage which include ablator, strut assembly, disconnects		X		
High Temperature Wind Tunnel - (similar to above)		X		
Cryogenic Test Area - Hazardous area to evaluate function performance of couplings, disconnects, etc.		X		

TABLE 3.3-5 FACILITY REQUIREMENTS LIST (Sheet 2 of 2)

Title and Description	New	Exist.	Contr.	Gov.
Test Facility for PTA - Main Engine test area	X			
External Tank Separation Demonstration - Area in which to perform full scale tank separation tests*		X		
LH_2 Fill Facility - Qual pressure vessel test		X		
Environmental Chamber - Hazardous area for Qual Testing LH_2 Disconnects and couplings		X		
Rocket Test Facility - SRM Testing		X		
Acoustic Chamber - Qualification Testing of nose fairing assembly		X		
Vibration System - Qualification Testing of nose fairing assembly		X		

* "A" frame at Langley under consideration.

3.4 THERMAL PROTECTION SYSTEM

The thermal protection system (TPS) is the key high risk area of the shuttle effort. State-of-the-art does not effectively exist as a viable tool and quantum steps must simultaneously be taken to select, justify, verify, qualify and convert to a cost and mission effective, durable, reliable, functional entity.

The TPS baseline is shown in Fig. 3.4-1, and is composed of the following major components:

- Metallic panels for major wing and fuselage surfaces
- External insulation TPS for lower elevon surface and small areas of fuselage and wing lower surface
- Carbon/carbon surface structure for fuselage nose, and wing and tail leading edge areas
- Internal insulation blankets for all fuselage surfaces and all metallic wing panels and leading edge areas
- Base heat shield will consist of metallic TPS to screen the load bearing structure from base flow stagnation gas temperatures

The metallic TPS shown in Fig. 3.4-2 is a shingled type radiative system consisting of a surface panel, an insulation package, and rib-standoffs, shielding the primary load carrying structure from the high surface temperatures. It is sufficiently stiffened to maintain an acceptable surface contour and smoothness while subjected to aerodynamic pressure loads and thermal gradients and supplies a high emittance surface for maximum radiation. TPS panel supports allow fore and aft motion during thermal expansion.

Rigidized external insulation, shown in Fig. 3.4-3, of a ceramic fiber material is bonded to titanium honeycomb substrates. Maximum operating surface temperature of the EI is 2500°F reducing to 600°F at the titanium interface. EI panels can be replaced using a system of removable plugs or internal access.

The system is designed to restrict the vehicle primary structure to 600°F, and the general internal temperature of the fuselage to 300°F during launch, reentry and landing maneuvers. It must also provide and preserve an acceptable vehicle outer surface aerodynamic contour.

Significant design features are:

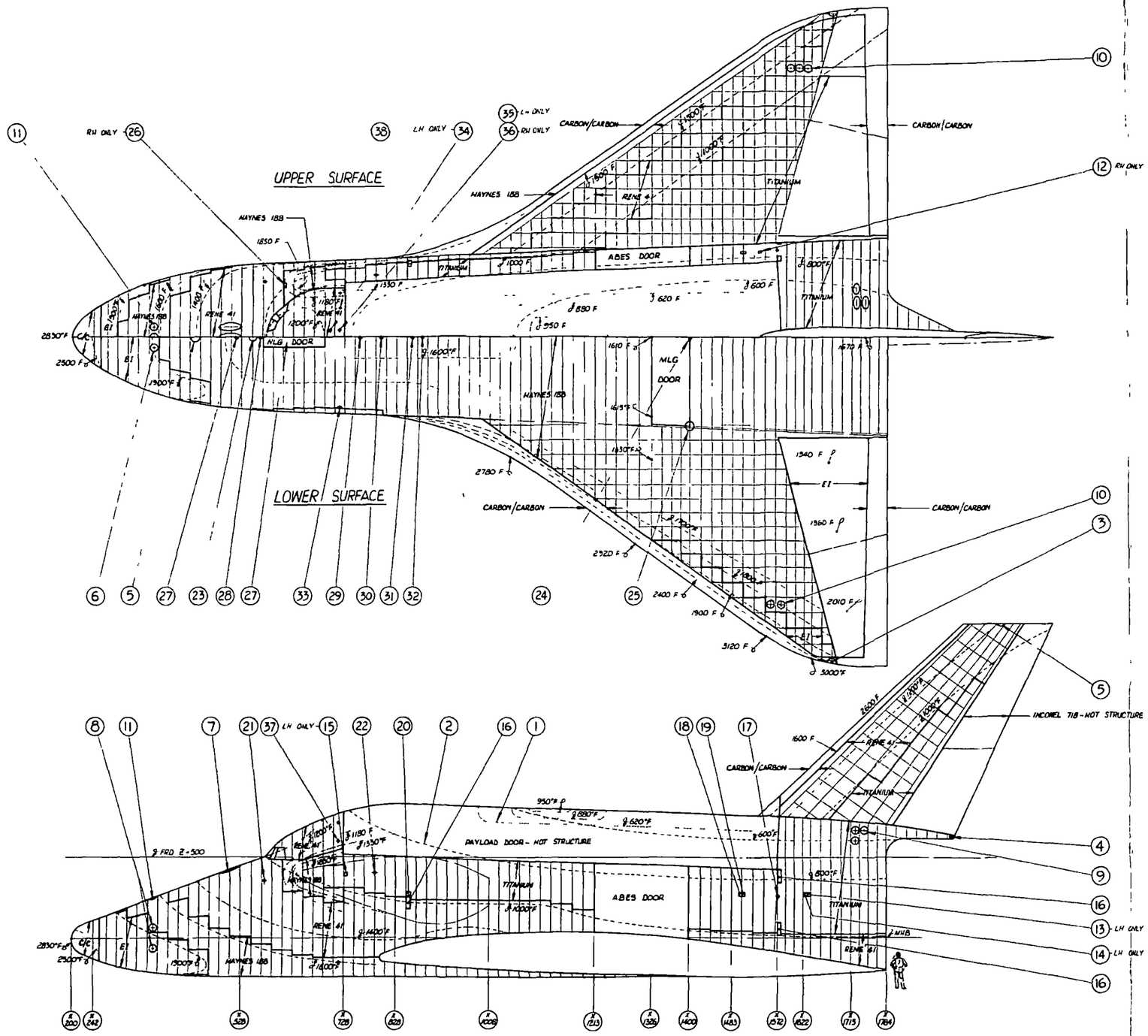
- All TPS components are reusable
- All components can be removed from the outside facilitating inspection and replacement
- The system is completely passive
- Nose, leading edge and lower surface TPS have large safety margin for one time exposure to overshoot design heating conditions
- Designed for 1100 n mi cross-range capability

Appropriate alternative materials will be investigated, developed, and qualified in parallel with the basic TPS designs. Backups are:

- Ablative for carbon/carbon
- Coated Columbian for EI
- Alternate forms of EI (i.e., HCF, 3DSX and CPI)

3.4.1 PERFORMANCE CHARACTERISTICS SUMMARY

Component	Max Use Temp °F	Design Life, No. Of Missions	Typical Unit Wt lb/ft^2
Metallic Panel			
Titanium	1000	100	1.0
Rene' 41	1600	100	1.7
Haynes 188	1800	100	2.5
Haynes 188	1900	25	2.8
External Insulation Panel	2500	100	3.5



NOTES

1. MAXIMUM ISOTHERMS ASCENT ---
2. MAXIMUM ISOTHERMS RE ENTRY - - - - -
3. WING POSITION LIGHTS
4. REAR POSITION LIGHT
5. ANTI COLLISION LIGHT
6. RCS THRUSTERS (2)
7. RCS THRUSTERS FWD (3)
8. RCS THRUSTERS (2 PER SIDE)
9. RCS THRUSTERS (3 PER SIDE)
10. RCS THRUSTERS (3) UPPER SURFACE, (2) LOWER SURFACE
11. RCS THRUSTERS (3)
12. SERVICE POINT LO_2 FILL/DRAIN
13. SERVICE POINT LH_2 FILL/DRAIN
14. SERVICE POINT JP_5 FILL/DRAIN
15. SERVICE POINT GH_2 GROUND VENT
16. PICK UP POINTS FOR LH_2 TANK SUPT RETRACTABLE SUPT STRUCTURE
17. VERTICAL SHEAR & DRAG ATTACHMENT LH_2 TANK
18. MAIN PROPELLANT FEED LINE
19. RECIRCULATION LINE LH_2
20. VENT PRESSURIZATION LINE
21. NON PROP VENT GO_2
22. NON PROP VENT GH_2
23. FWD INTERSTAGE FITTING
24. AFT INTERSTAGE SIDE LOAD FITTING
25. AFT INTERSTAGE DRAG LOAD FITTING
26. GO_2 GROUNDVENT
27. KU BAND SCANNING BEAM ANTENNA - (2 INSIDE SURFACE NOSE WHEEL DOOR)(1 BOTTOM ℄)
28. S BAND O/B ANTENNAS (2)
29. TACAN ANTENNA
30. L BAND ATC ANTENNA
31. C BAND ALTIMETER ANTENNAS (6)
32. VHF ATC ANTENNA
33. S-BAND COMM ANTENNAS
34. L BAND ATC ANTENNA
35. VHF ATC ANTENNA
36. TACAN ANTENNA
37. VHF TDRS ANTENNA
38. S BAND COMM ANTENNA

Fig. 3.4-1 H-32 General Arrangement Thermal Protection System

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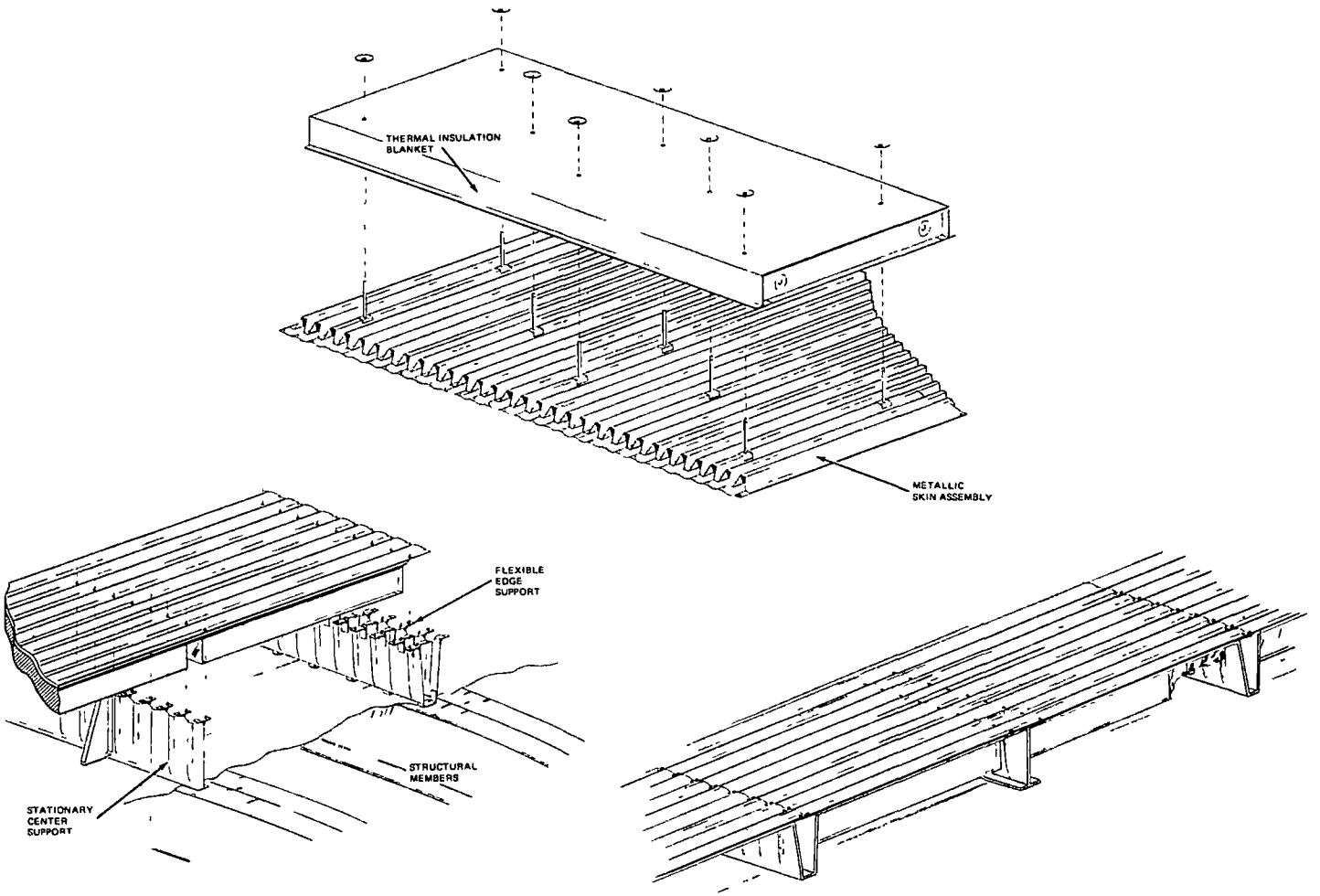

Fig. 3.4-2 Typical Metallic Panel Design

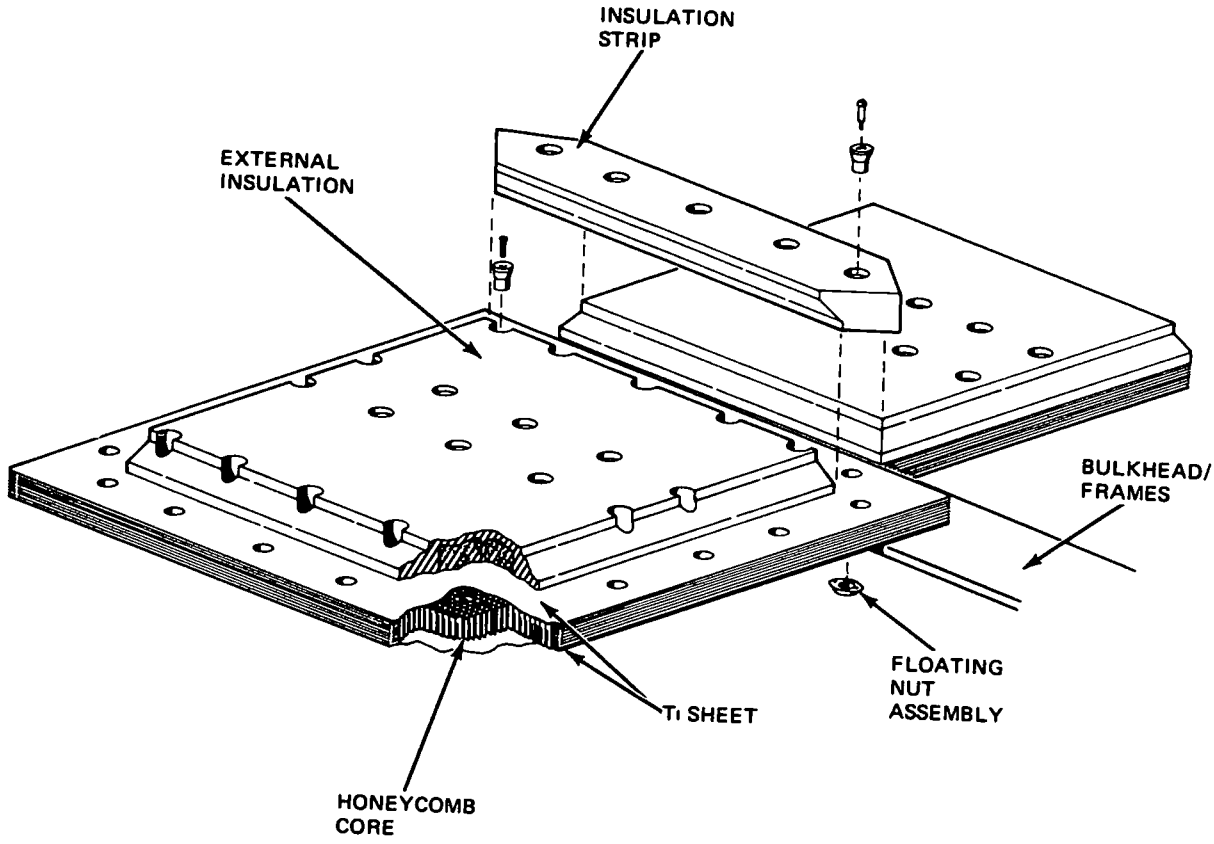

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Fig. 3.4-3 Typical External Insulation Panel

Component	Max Use Temp °F	Design Life, No. Of Missions	Typical Unit Wt lb/ft^2
Carbon/Carbon Leading Edge & Nose	3000	100	5.0
Internal Insulation Blanket			
Glass	1000	100	
Quartz	1800	100	
Quartz	1900	25	
Alumino-Silicate	2300	25	
Zirconia	3000	25	

3.4.2 RISK IDENTIFICATION AND RESOLUTION

The major development risks in all areas presented, hinge on selection of the correct materials, accuracy of thermal plots, design adequacy, reliability and weight/cost effectiveness. To effectively resolve these risks, an in-depth program has been instituted, a major pivot of which is the parallel development of contingency or backup materials and/or designs for all of the areas involved.

For example, carbon/carbon applications will be backstopped by interim ablative treatment, while coated refractory candidates will be pursued to the depth and stage necessary to ensure satisfactory phase in and use if and when required. Insulation packaging will be optimized for life and resistance to physical damage.

In all TPS types, elimination of joint leakage will be considered a primary design requirement and pursued throughout the test schedule to assure design success and practicality.

Maximum mission life and reusability are heavily stressed. All panels are removable and replaceable, and in addition to standard NDT techniques (i.e., x-ray, ultrasonics, dye penetrant, etc.), removal of selected panels will permit visual inspection of areas of the substructure exterior and TPS inner surface during normal inter-mission servicing periods.

Another unique and extremely critical design challenge is the elevon seal. During hypersonic phase deflections, hot boundary layer gas must be excluded from the aft face portion of the rear wing beam. Potential solution utilizing Columbium and superalloy wiper seals have been examined.

The risk resulting from local interference heating between the external LH_2 tanks and the fuselage is resolved by ablative spray coating on affected areas of the tank. Increased temperature effects on the fuselage and wing are resolved by the use of appropriate metallic TPS panels.

Vortex reattachment from the external tank nose has been identified and located. The area affected on the fuselage is localized in the approximate fore and aft center of the cargo compartment doors. Since the doors are replaceable and not primary structure and the condition is extremely transient, the present titanium structure will be permitted to accept this exposure. Should this simple inexpensive risk solution prove unacceptable, the backup is elimination of the risk by the use of a nickel base alloy in the affected portion.

In conjunction with the development of the final operational TPS configuration and to assure earliest flight availability, an interim all aluminum TPS panels will be designed for the horizontal flight test program only. This system will be similar to the TPS in terms of roughness, discontinuity and shape with sufficient margins of safety to eliminate development testing.

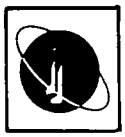
This considerably less expensive facsimile than the final TPS will significantly reduce development risks by permitting a more thorough and deliberate TPS program. This approach will minimize possible large duplicate costs for sophisticated tooling of a less adequate design generated by milestone pressures that can hereby be deferred and thus guarantee an undamaged, maximum life, best configuration mated suit of TPS for the critical first manned orbital flight. Demand pressures on critical, expensive, otherwise congested test facilities can also be most effectively minimized and more smoothly scheduled for optimum work flow, while equally critical financial budgetary flow can be spread more evenly and over a longer fiscal span.

All TPS panel tests will be preceded by structural, creep, and flutter analysis and materials screening. Design, development and verification tests will evaluate static strength cumulative creep characteristics and acoustic and repeated loads fatigue life.

Panel oxidation rates and joint seal characteristics under high velocity gas flow conditions will be evaluated in contractor and NASA arc jet facilities. Panel flutter tests at elevated temperatures will be performed in the high temperature structure tunnel (HTST) at Langley.

Instrumentation will define temperature distribution, hot gas leakage, structural deflection and creep, stress and dynamic response as appropriate. All phases will be fully documented with applicable tables, graphs, photos, time histories and procedures. A brief description of the test approach to risk resolution, verification and qualification follows:

- Materials selection/development tests to determine suitability for TPS application of candidate materials. Screening on a coupon level will include erosion, toughness, temperature cycling, humidity, bond strength, material life, and workability data
- Design feasibility of TPS panels will establish basic structural adequacy in the flight environment resulting in finalizing material and design compatibility. Representative tests on panel elements will involve shear, torsion, bending and/or pressure, temperature, etc
- TPS panel hypersonic test for mission life, heat transfer performance and structural adequacy under closely simulated reentry environment by testing in hypersonic wind tunnel up to 3000°F
- TPS temperature/acoustic test for mission life structural adequacy when exposed to the combined noise, temperature environment peculiar to reentry. This is a critical high risk design condition requiring verification
- TPS vibration/temperature test for boost vibration effects resulting from booster and orbiter engine operation in combination with elevated temperatures form aero heating. This critical design test will use the same facility required for base heat shield and engine insulation testing



- TPS moisture absorption test for prediction of orbiter performance during boost and horizontal flight since performance is based upon an accurate estimate of weight increase resulting from high humidity and/or rain exposure, verification of design parameters is imperative
- Moisture erosion tests will establish adequacy of erosion resistance for the TPS life. Erosion is a critical environment during horizontal, subsonic flight
- Temperature-load tests under simulated reentry heating and air loads are critical structural design conditions. Combined temperature load tests demonstrate structural adequacy of both panels and support structure useful life and performance of expansion joints, seams and seals
- Acoustic test for ability of the TPS to survive the noise levels resulting from booster engine operation during pre-launch is to be demonstrated by acoustic testing at room temperature. This test combined with the temperature/acoustic test described above minimizes a high risk area verifying design adequacy to these two critical conditions
- Panel Vent - Since pressure loadings on the TPS panels during launch and boost and during reentry are partially determined by the performance of vents which equalize pressure between orbiter internal volume and local ambient and between panel interiors and orbiter internal volume, the adequacy of these vents will be demonstrated by subjecting TPS panel and vents to pressure transients similar to launch and reentry
- Thermal/Vacuum Test - Verification of the analytical thermal balance of the orbiter through determination of space heat leak characteristics of TPS by measurement of heat leak in a thermal/vacuum environment
- Thermal Reentry Heat Flow - Transient heat flow rate through the TPS will determine structural temperature rise during the reentry phase. These heat flux rates will be derived experimentally in the same facility used for temperature load testing

- Temperature/Pressure Acoustic Test - This test combines the temperature, pressure and noise levels of TPS temperature/acoustic test and temperature load as described above. The combined environments are a high risk area and will be more severe than individual environments. Therefore, to minimize risk, this test will be conducted under a certification technique whereas TPS temperature/acoustic and temperature load tests will demonstrate for feasibility and verification

- Vibration/acoustic/pressure test combined environment at launch produces a critical design condition despite off-peak individual environmental parameters. Addition of a pressure controlled compartment to the facility required for TPS temperature/acoustic test will accomplish this task

- Temperature/flutter test off-peak flutter combined with elevated temperatures creates a severe design condition during reentry and will be investigated and resolved to guarantee structural adequacy

- TPS Seal Gas Infiltration and Heating Test - TPS panel weights and thickness are determined by the heat flow into the base structure. This hot gas leakage past the seals must be determined to finalize design, and will be determined by measuring the leakage through a typical panel sealing edge heated to reentry temperatures under the specified pressure differential

3.4.3 CERTIFICATION TEST PROGRAM

The previously identified materials and forms of TPS will be evaluated in depth to select the optimum configuration for mission use. These tests will be supported by extensive work already accomplished, in progress, and planned throughout the industry and by NASA. Screening tests will preceed all feasibility effort to avoid costly false starts and reduce development risks.

In the area of external insulation, tests of a mullite closed porosity insulation (CPI), and coated woven batts will run concurrently with design feasibility tests of fiberous systems over the initial year's period. Development tests of the successful candidates will continue through with qualification tests of the final configuration to be complete before installation on the first orbital flight.

The same approach will be followed for carbon/carbon applications. When sufficient data has been acquired for a weight cost effective decision, feasibility tests will be terminated and design development testing of approximately six months span will begin, culminating in qualification tests before the first orbital flight vehicle installation. Ablative materials and designs will be investigated in sufficient depth to reduce risks and provide an effective backup to the reusable system.

Similar efforts will be applied over the entire range of metallic candidates; i.e., titanium, Rene' 41, Haynes 188, and coated columbium. Screening tests will be run in parallel, moving through design feasibility to design development testing of selected panels. Qualification testing will run concurrently on all final alloys and configurations to permit installation on the first orbital vehicle. Appropriate internal insulation development and qualification will accompany each design.

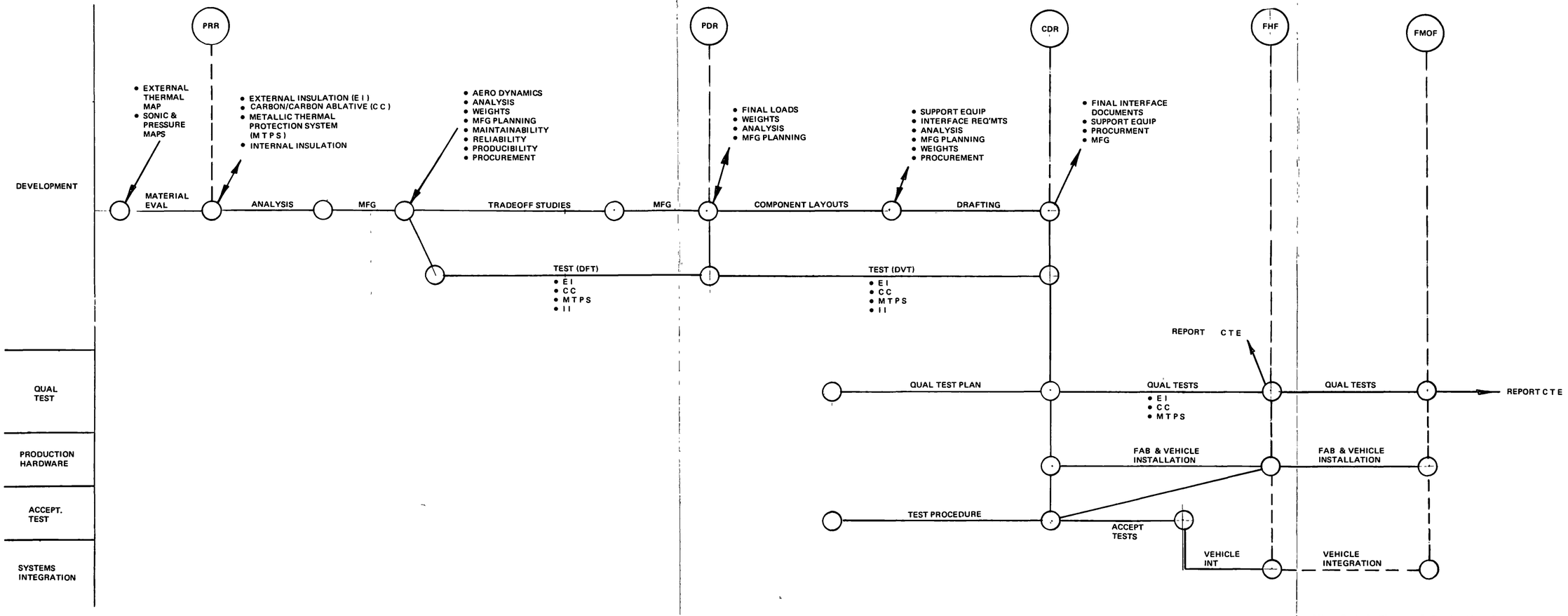


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Fig. 3.4-4 Thermal Protection System Logic

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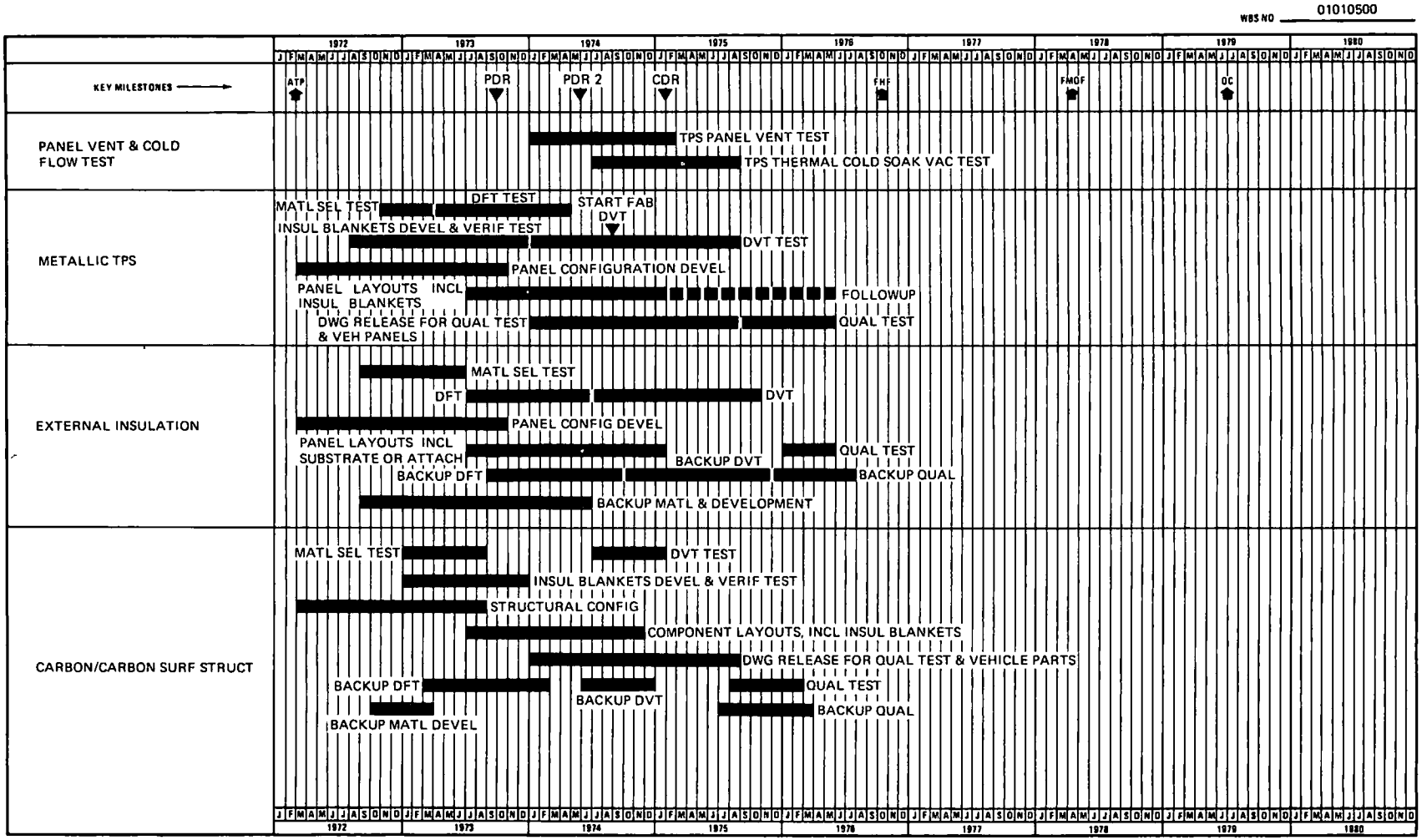

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Fig. 3.4-5 Thermal Protection System Schedule

THERMAL PROTECTION SYSTEM

TABLE 3.4-1 SUBSYSTEM CERTIFICATION REQUIREMENTS

Certification Requirement	Certification Method						Level of Assembly				
	Analysis	Simulation	Similarity	Common Usage	Test		Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
					DVT	Qual					
Evaluate Candidate Materials (Selection/ Development)	X		X		X		X				
Design Feasibility TPS Panels (Metallic, EI, Carbon/Carbon) Tests					X		X	X			
TPS Panel Hypersonic Test					X	X		X			
TPS Panel Temp/Acoustic Test					X			X			
TPS Panel Vibration/Temp Test					X	X		X			
TPS Panel Moisture Absorption Test					X	X		X			
TPS Panel Moisture/Erosion Test					X	X		X			
TPS Panel Temp/Load Test					X			X			
TPS Panel Acoustic Test					X	X		X			
TPS Panel Vent Test	X				X			X			
TPS Panel Thermal Vacuum Test	X				X			X			
TPS Panel Thermal Reentry Heat Flow Test	X				X			X			
TPS Panel Temp/Pressure/Acoustic Test					X	X		X			
TPS Panel Vibr/Acoustic/Pressure Test					X	X		X			
TPS Panel Elevator Temp Flutter Test					X	X		X			
TPS Seal-Gas Infiltration & Heating Test					X			X			

TABLE 3.4-2 MAJOR COMPONENT LIST (BASELINE)
(Sheet 1 of 3)

Fuselage TPS Surface Panels

Temp Range, °F	Panel Material	Area, Ft^2	Avg Panel Size, In.	Avg Panel Area, Ft^2	Orbiter No. of Panels
600 - 1000	Ti 6-2-4-2	2340	40 x 96	26.67	89
1000 - 1600	Rene' 41	1579	40 x 96	26.67	60
1600 - 1900	HS-188	3574	40 x 96	26.67	134
1900 - 2500	EI	373	40 x 40	11.1	34
2500 - 3200	Carb/Carb	80	120 Dia Hemisphere		1

Wing TPS Surface Panels

1000	Ti 6-2-4-2	644	40 x 96		25
1000 - 1600	Rene' 41	640	40 x 96		24
1600 - 1900	HS 188	2127	40 x 96		80
1900 - 2500	EI	138	40 x 40		13
2500 - 3200	Carb/Carb	696	30 long		120
LE & Fairing					

Elevon TPS Surface Panels

1000	Ti 6-2-4-2	540	40 x 96		21
1000 - 1600	Rene' 41	111	40 x 96		5
1940 - 2010	EI	688	40 x 40		62
Trailing Edge	Carb/Carb	249	TBD		

Vertical Fin Surface Panels

1000	Ti 6-2-4-2	323	40 x 96	26.67	13
1000 - 1600	Rene' 41	722	40 x 96	26.67	28
2500+	Carb/Carb	125	30 long		20
Leading Edge					

TABLE 3.4-2 MAJOR COMPONENT LIST (BASELINE)
(Sheet 2 of 3)

Doors

Nose L.G. one split door 50 in. x 120 in. overall

Main L.G. two doors 80 in. x 150 in.

ABES doors 150 in. x 180 in.

LH_2 tank attach and feed, 12 doors, approx. 10 in. x 20 in.

Interstage attachment, 4 doors, 20 in. x 20 in.

Misc. fill/drain, vent, 7 doors, 10 in. x 10 in.

C-band antenna 24 in. dia

Window Covers

Cockpit 6 covers approx. 20 in. x 20 in.

Antennas

S-band (2)	HS-188	15 in. x 10 in. ea.
Tacan	HS-188	15 in. x 10 in.
L-Band	HS-188	8 in. Dia.
VHF	HS-188	4 in. x 24 in.
S-Band	HS-188	15 in. x 10 in.
L-Band	Rene 41	8 in. Dia.
VHF	Rene 41	4 in. x 24 in.
Tacan	Rene 41	
VHF TDRS	Rene 41	4 in. x 24 in.

TABLE 3.4-2 MAJOR COMPONENT LIST (BASELINE)
(Sheet 3 of 3)

INSULATION BLANKETS

Temp Range, °F	Panel Material	Area, Ft^2	Avg Panel Size, In.	Avg Panel Area, Ft^2	Orbiter No. of Panels
Fuselage					
600 - 950 (cargo doors)	TG-15000	1326	24 x 144	24.0	56
600 (EI Panels)	TG-15000	373	20 x 40	5.55	68
600 - 1000 (Ti Panels)	TG-15000	2340	20 x 96	13.35	176
1000 - 1900 (Rene' 41 & HS-188	Micro-Quartz	5153	20 x 96	13.35	386
2500 - 3200	Zirconia Felt	80	60 R Quad	20	4
Wing					
600 - 1000 (Ti Panels)	TG-15000	644	20 x 96	13.35	49
1000 - 1900 (Rene' 41 and HS-188)	Micro-Quartz	2767	20 x 96	13.35	208
2500 - 3200 LE & Fairing	Zirconia Felt		24 x 30		120
Elevon					
1000	TG-15000	540	20 x 96	13.35	41
1000 - 1600	Micro-Quartz	111	20 x 96	13.35	9
Vertical Fin					
1000	TG-15000	323	20 x 96	13.35	26
1000 - 1600	Micro-Quartz	722	20 x 96	13.35	55
2500+	Zirconia	125	20 x 30		20

TABLE 3.4-3 MAJOR COMPONENT LIST (BACKUP SYSTEM)
(Sheet 1 of 2)

SURFACE PANELS

Fuselage

Temp Range, °F	Panel Material	Area, Ft^2	Avg Panel Size, In.	Avg Panel Area, Ft^2	Orbiter No. of Panels
600 - 1000	Ti 6-2-4-2	2340	40 x 96	26.67	89
1000 - 1600	Rene 41	1579	40 x 96	26.67	60
1600 - 1900	HS-188	3574	40 x 96	26.67	134
1900 - 2400	WC-103	373	20 x 20	2.78	134
2400 - 3200	Ablative	80	120 Dia. Hemisphere		1
		Wing			
1000	Ti 6-2-4-2	644	40 x 96		25
1000 - 1600	Rene 41	640	40 x 96		24
1600 - 1900	HS-188	2127	40 x 96		80
1900 - 2400	WC-103	138	20 x 20		50
2400 - 3200	Ablative	696	30 long		120
		Elevon			
1000	Ti 6-2-4-2	540	40 x 96		21
1000 - 1600	Rene 41	111	40 x 96		5
1940 - 2100	WC-103	688	20 x 20		247
Trailing Edge	WC-103	249			
		Vertical Fin			
1000	Ti 6-2-4-2	323	40 x 96	26.67	13
1000 - 1600	Rene 41	722	40 x 96	26.67	28
2500+	Ablative	125	30 long		20

Doors, Windows, Antennas - Same as baseline

TABLE 3.4-3 MAJOR COMPONENT LIST (BACKUP SYSTEM)
(Sheet 2 of 2)

INSULATION BLANKETS

Fuselage

Temp Range, °F	Panel Material	Area, Ft^2	Avg Panel Size, In.	Avg Panel Area, Ft^2	Orbiter No. of Panels
600 - 950 (Cargo Doors)	TG-15000	1326	24 x 144	24.0	56
600 - 1000 (Ti Panels)	TG-15000	2340	20 x 96	13.35	176
1000 - 1900 (Rene 41 and HS-188)	Micro-Quartz	5153	20 x 96	13.35	386
1900 - 2400 (WC-103)	Dynaflex-Micro-Quartz	373	10 x 20	1.39	268
600 (Ablative)	TG-15000	80	60 R Quad	20	4

Wing

600 - 1000 (Ti Panels)	TG-15000	644	20 x 96	13.35	49
1000 - 1900 (Rene 41 and H-188)	Micro-Quartz	2767	20 x 96	13.35	208

Elevon

1000 - 1600	Micro-Quartz	111	20 x 96	13.35	9
1940 - 2010 (WC-103)	Dynaflex-Micro-Quartz	688	10 x 96	1.39	494
1000	TG-1500	540	20 x 96	13.35	41

Vertical Fin and Rudder

1000	TG-15000	323	20 x 96	13.35	26
1000 - 1600	Micro-Quartz	722	20 x 96	13.35	55

TABLE 3.4-4 REQUIRED EQUIVALENT UNITS

Hardware Description	Required Equiv. Units
Flight Hardware Per Vehicle	9 full sets panels 17 sets leading edges
Component Devel & Qual Test	1/2
Integration Tests	
• Full Mission Simulation Lab	
• Integrated Avionics Test Lab	
• Flight Controls Hydraulic Test Lab	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	
Test Articles	
• Propulsion Test Article*	3
• Structural Test Article	
Spares for Flight Test Program	1
Spares for 445 Flights	9

*PTA Requires one special base heat shield (may be water cooled)

TABLE 3.4-5 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

Item	Requirements
Support Equipment	Support stands (Hor & Vert Erect) Access stands Slings, dollies, jacks Component support fixture (install) Component protective devices Reusable containers Tools & fixtures for installation Rigging devices TPS panel hypersonic test rig for vib/temp test Press./temp./acoustic test rig Scale to measure weight of panels Deflection probes and transducers CSC systems for recording deflections and temperatures Diff. press. transducers and readouts Hydraulic rig and control valve to simulate altitude-time profile Main heater and guard heater assembly for effective emittance measurements plus thermocouples and readouts Ammeters and voltmeters Insulated heat sink Quartz array, pressure sealing fixture, supply tank, piping, control valves, heat and flow meter for gas infiltration and heating test
Software	None

TABLE 3.4-6 FACILITY REQUIREMENTS LIST
(Sheet 1 of 3)

Title and Description	New	Exist.	Contr.	Govt
Temp/Load Test - TPS Panels - Up to 40 x 40 in. 2 required: (1) 40 x 40 in. spec to 1900°F (Panel holding fixture to be fabricated)	X		X	
(2) 20 x 20 in. spec to 2500°F		X	X	
Floor Space: 10 x 15 ft		X	X	
Power Required: 70 kw (New lamp array to be fabricated)	X		X	
Data Acq		X	X	
Acoustic Test - TPS Panels - Up to 20 x 40 in. acoustic spectrum range req. of 130 to 148 db between 60 and 10,000 Hz		X	X	
Floor Space: 15 x 20 ft		X	X	
Power Required: Nominal		X	X	
Data Acq		X	X	
TPS Panel Vent Test Rig - 8 x 34 ft vacuum chamber with 15 x 20 ft vacuum chamber as an auxiliary		X	X	
Floor Space: 40 x 100 ft		X	X	
Hydraulic Rig required		X	X	
Data Acq: Bristol Recorder		X	X	
Thermal Vacuum Test - 4 x 8 ft vacuum chamber with LN_2 cold walls		X	X	
Floor Space: 10 x 15 ft		X	X	
Data Acq: Bristol Recorder		X	X	
Thermal Reentry Heat Flow Test - insulated heat sink				
Heat Sink (Insulated plate with T/C's to be fabricated)	X		X	
Floor Space: Previously noted				

TABLE 3.4-6 FACILITY REQUIREMENTS LIST
(Sheet 2 of 3)

Title and Description	New	Exist.	Contr.	Govt
TPS Panel Hypersonic Test Rig - Gas flow at hypersonic velocities with a stagnation temp of 3000°F -				
2 required: (1) with pure air & 2 x 4 ft spec size (WPAFB 50 mw arc jet)		X		X
(2) with 3-1/2 x 5 ft specimen size (LRC 8 ft HTST)		X		X
Floor Space: 100 x 150 ft		X		
Power Required: 50 mw (Facility (1) only)		X		
Data Acq		X		
TPS Panel Temp/Acoustic Test Rig - 3-1/2 x 5 ft panel requiring an octave band level of 130 to 148 db between 60 and 10,000 Hz with a max. temp. of 2500°F		X	X	
Floor Space: 10 x 15 ft		X	X	
Power Req'd (1.5 mw supply, control & lamp array required)	X		X	
Data Acq		X	X	
Vibration/Temperature Test - TPS Panels - Up to 3-1/2 x 5 ft with temperatures up to 2500°F				
Vibration Facility		X	X	
Temperature Facility (New lamp assembly to be fabricated)	X		X	
Floor Space: 15 x 15 ft		X	X	
Power Required: (1.5 mw)		X	X	
Data Acq		X	X	
Moisture Absorption Test - TPS Panels-Up to 2 x 4 ft		X	X	
Floor Space: 10 x 10 ft		X	X	
Data Acq		X	X	

TABLE 3.4-6 FACILITY REQUIREMENTS LIST
(Sheet 3 of 3)

Title and Description	New	Exist.	Contr.	Govt
Moisture Erosion Test - TPS Carbon/Carbon, ablative & Rigid External Insulation Panels - Up to 2 x 4 ft subsonic velocities with entrained moisture (Appropriate wind tunnel)				
Floor Space: 100 x 50 ft		X	X	
Power Required: Nominal		X	X	
No Data Acq		X	X	
TPS Panel Temp/Press/Acoustic Test Rig - Add a press. controlled compartment to the Temp Acoustic Test Facility	X		X	
Floor Space: Previously noted				
TPS Panel Vibration, Acoustic, & Press. Test Rig - Add press. controlled compartment and vibration facility to Acoustic Test Facility	X		X	
Floor Space: Previously noted				
TPS Seal Gas Infiltration and Heating Test - 15 x 20 ft vacuum chamber with LN_2 cold walls				
Supply tank, piping, control valves, heater, flow meter, quartz array, and pressure sealing fixture	X		X	
Floor Space: 40 x 50 ft		X	X	
Power Required: 1.0 mw		X	X	
Data Acq.		X	X	

3.5 CREW STATION EQUIPMENT AND PASSENGER ACCOMMODATIONS

The structurally integral pressure compartment contains all the facilities for a habitable volume for the crew and passengers. This volume is large enough to accommodate a flight crew of four, two passengers and additional volume for eight passengers with temporary facilities, an airlock and required appointments to fulfill mission requirements.

A baseline flight station of four operational crewmen is conventionally arranged to accommodate the flight commander, pilot and two crew members closely integrated to perform tasks to be defined by systems and subsystems task analysis and mission profiles. The display and controls arrangement provides shared and duplicate functions allowing either man to fly the space plane in an emergency. The powered seats are adjustable to orientate the operators in the conventional aircraft and spacecraft positions. The window arrangement permits a 20° over the nose vision sufficient to view the landing aids during powered and unpowered approaches and vision in other quadrants to fulfill the total mission profile. A right hand controller is used as a three axis space and two axis aerodynamic device while the left hand control is used for three axis translation in space and single control lever for the airbreathing engines. A power quadrant on the center console is used for engine start and run up.

Two additional passenger seats can be placed abreast (optional arrangement) of the two rear crew men to form the nucleus of a six man flight station to manage a large percentage of the projected flights which will be validated in subsequent parametric crew loading studies. The mid section of the pressurized compartment contains eight to ten passenger seats, easily positioned in flight by the crew to support passengers during all critical flight modes. When removed, this volume is used by the four to six man crew for rest and diversion on the extended seven day mission. The airlock located at the end of the cabin compartment connects directly to the payload interconnecting tunnel. This compartment is sized to accommodate two suited men with full complement of EVA gear, a waste management and galley area. During normal mission modes, this compartment can

be used for food preparation and also provide privacy for male and femal occupants when utilizing the waste management system.

The docking maneuver is performed by a shirt sleeved technician located in the upper portion of the compartment using auxiliary controls. Opening the cargo doors, the technician can view, through a window, the airlock, the payload deployment and the docking operation.

Hatches will be provided for all modes of ingress/egress from the pressure compartments; two located in the airlock, one providing access during ground and EVA modes and the other for access to the payload; two hatches located in the mid cabin section for passenger access and an overhead hatch in the upper compartment for use by the crew during launch pad mode and emergency exit on the deck.

Internal appointments provide handgrips and mobility devices permitting movement during all phases of the mission. Volume is provided for storage of avionics, EC/LSS, CFE and GFE hardware.

Mockups as described in subsection 10.1 will play a valuable part in the development of the crew and passenger compartment and its associated hardware which directly interfaces with the operators. Inputs from the various design disciplines, associated contractors and NASA will initiate the early preliminary layouts with outputs to the mockup and hardware developments. Solidarity and confidence in the design will be satisfied through reviews by the customer and close harmony with interfacing disciplines and experienced consulting pilots and astronauts. Updating of the design will be a fall out of each review coupled with DFT's and DVT's of the development hardware. Preliminary hardware "look-see's" will be evaluated by spot checks on their interfaces to effectively ensure man-interface compatibility throughout the mockup and engineering development phase. Further verification of hardware will be dynamically evaluated during KC-135 and neutral buoyancy test programs to effect design changes prior to FMOF. Such items as lighting, maintainability, commonality will be stressed and monitored through logical subsystems inputs.

The arrangement of this subsystem is shown in Fig. 3.5-1.

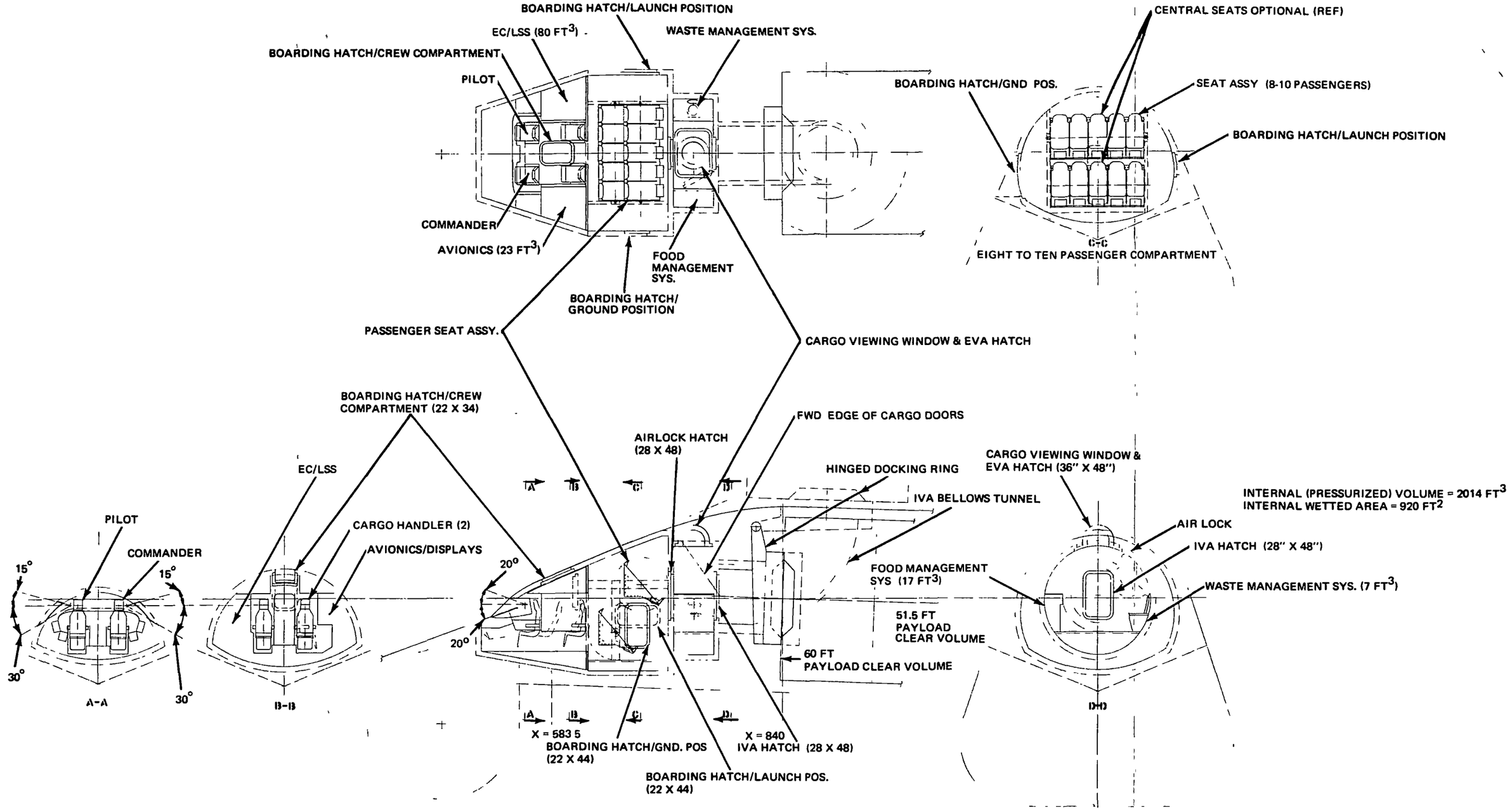

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Fig. 3.5-1 14-Man Cabin Layout Configuration

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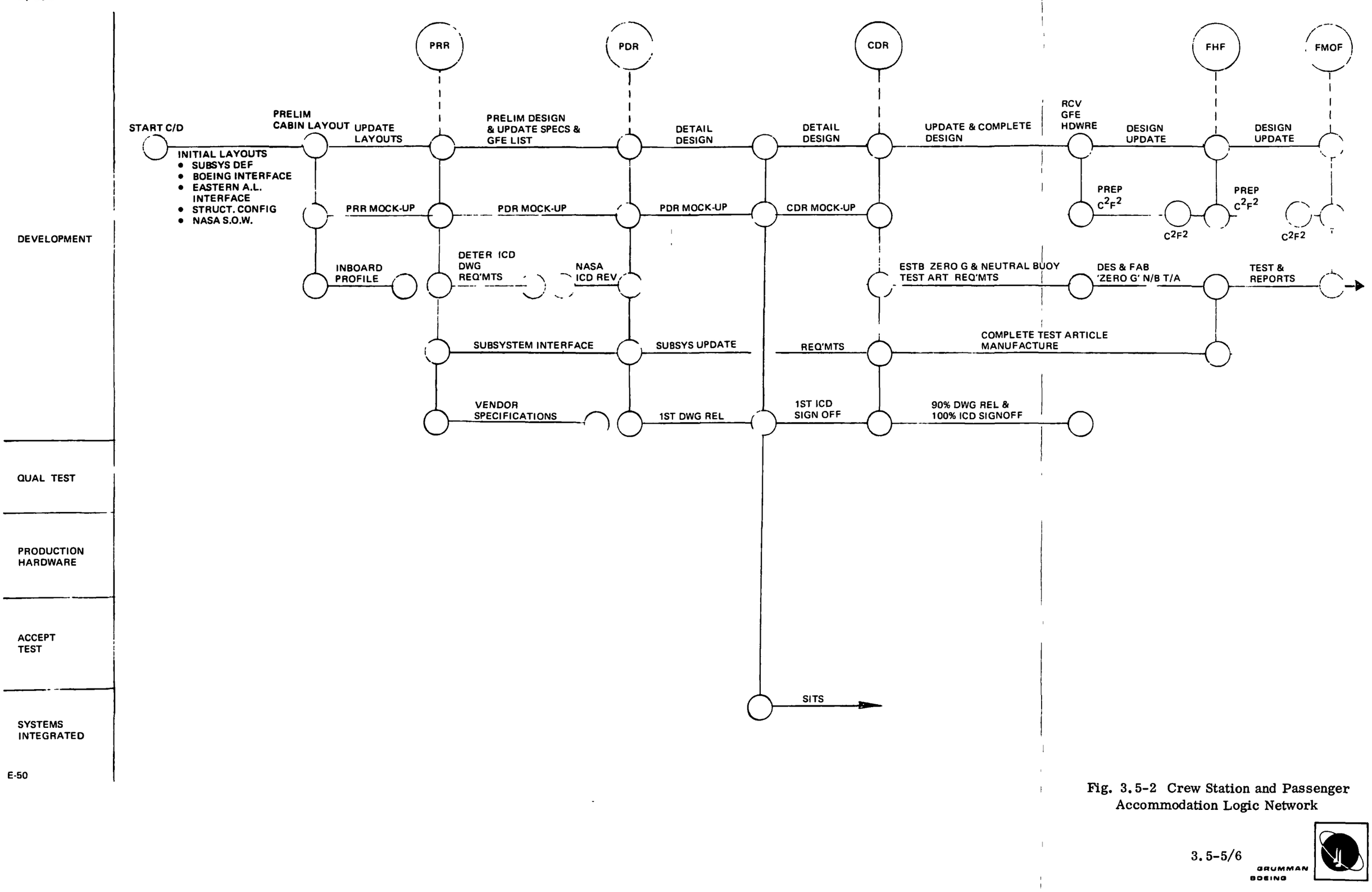

Fig. 3.5-2 Crew Station and Passenger Accommodation Logic Network

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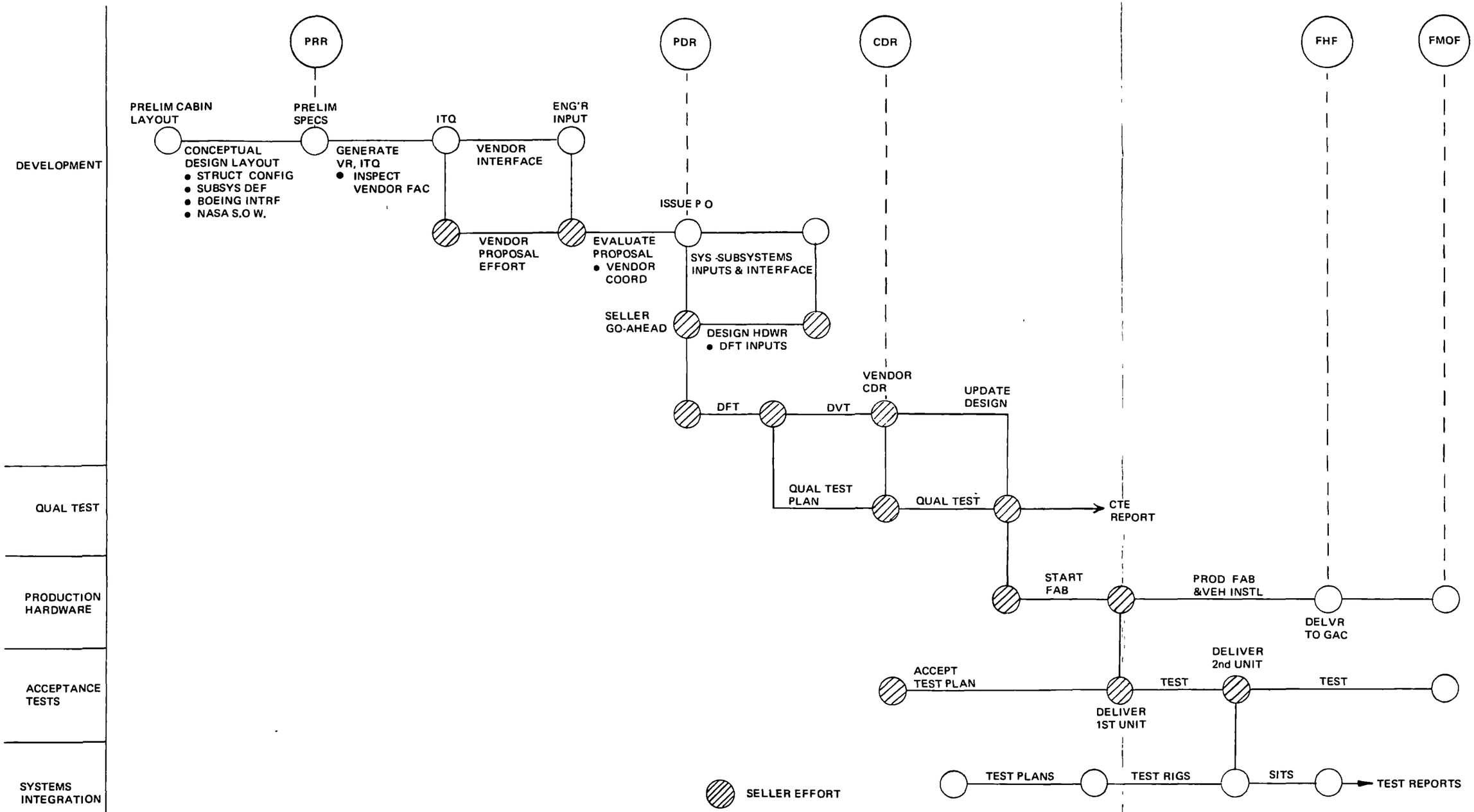

Fig. 3.5-3 Crew Station and Passenger Accommodation Logic Network

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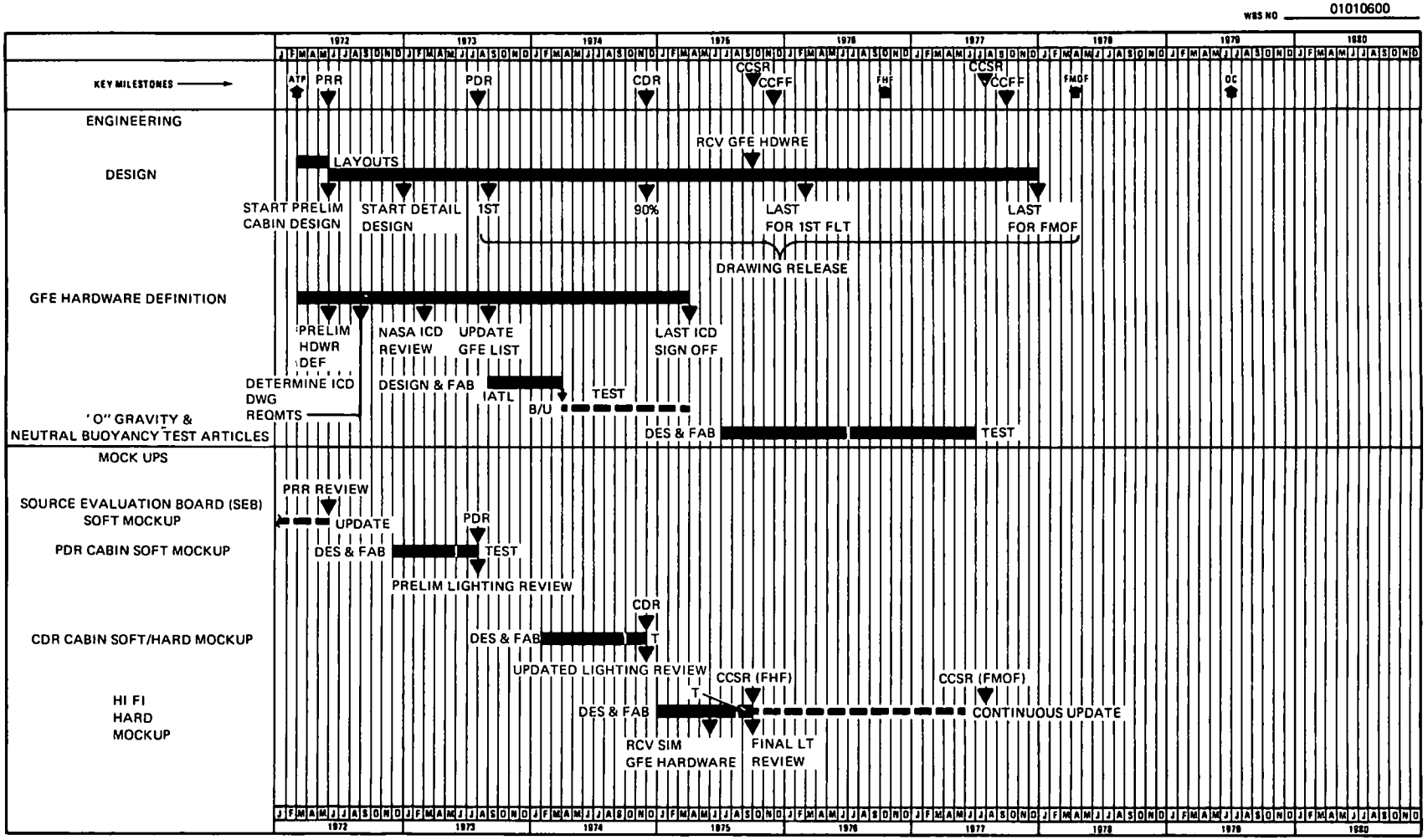

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Fig. 3.5-4 Crew & Passenger Accommodations Schedule (Sheet 1 of 2)

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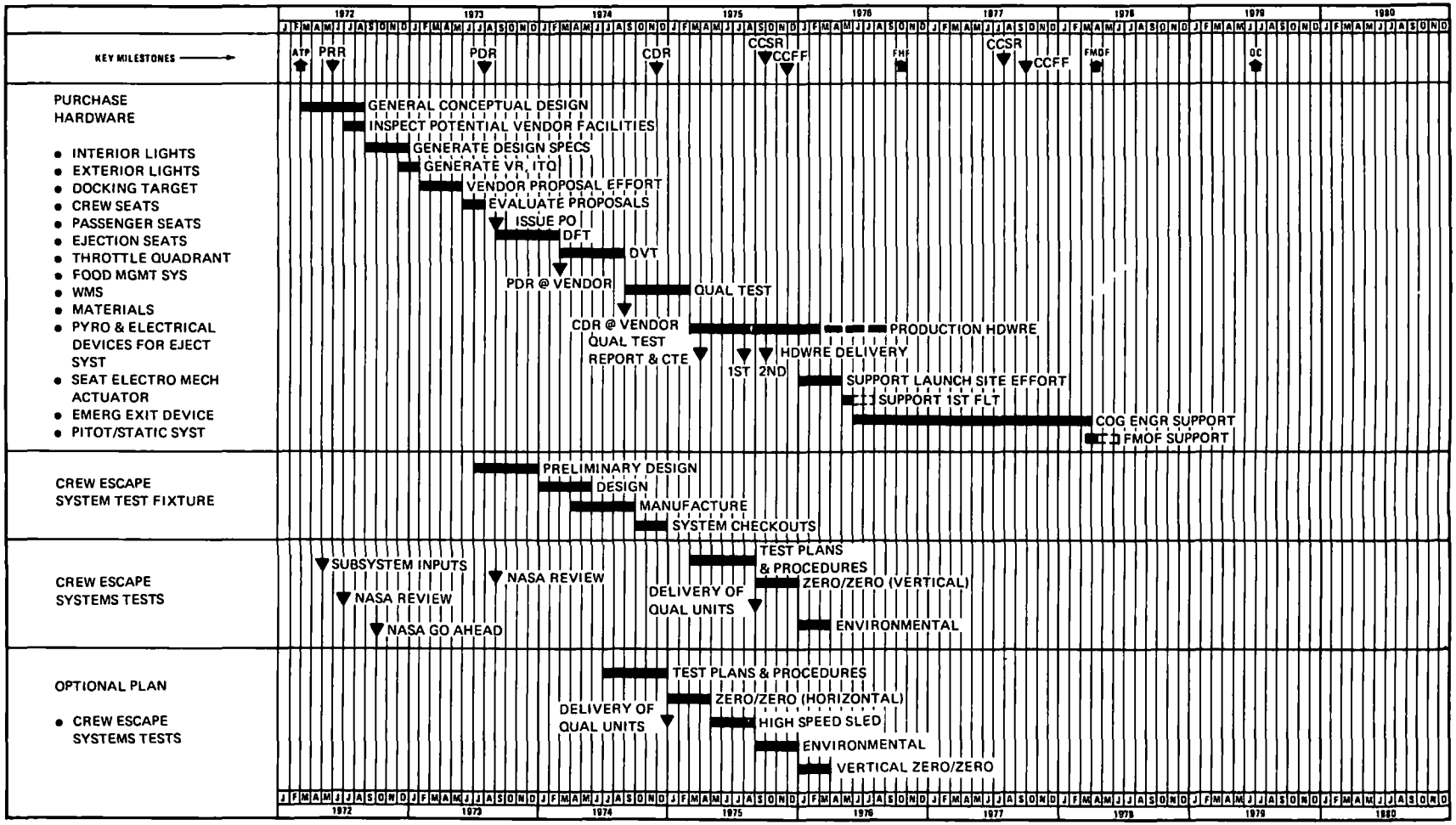

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Fig. 3.5-4 Crew & Passenger Accommodations Schedule (Sheet 2 of 2)

TABLE 3.5-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 1 of 7)

Certification Requirement	Certification Method						Level of Assembly				
	Analysis	Simulation	Similarity	Common Usage	Test		Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
					DVT	Qual					
Verify that:											
I. Seats-Production configuration											
1. Structural integrity under specified flight, contingency load and environment conditions											
a. Flight Crew					X	X		X			
b. Technician Station					X	X		X			
c. Passenger					X	X		X			
2. Structural Integrity of seat-to-structure attachment fittings under specified load conditions											
a. Flight Crew					X	X				X	
b. Technician Station					X	X				X	
c. Passenger					X	X				X	
3. Structural integrity of seats during anticipated personnel ingress/ egress, operation, handling, installation/removal conditions											
a. Flight Crew					X	X			X		
b. Technician Station					X	X			X		
c. Passenger					X	X			X		

TABLE 3.5-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 2 of 7)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
4. Functional Operation of seats in compliance with spec reqmts (ie. adjustment, position, design eye panel and control reach, etc.)											
a. Flight Crew	X	X							X		
b. Technician Station	X	X							X		
c. Passenger (partial test)	X	X							X		
II. Crew Seats - Flight Test Configuration*											
1. Structural integrity under specified flight, contingency load & environment conditions					X	X				X	
2. Structural integrity of seat-to-structure attachment fittings under specified load conditions					X	X				X	
3. Structural integrity of seats during anticipated personnel ingress/egress, operation, handling, installation/removal conditions					X	X			X		
4. Functional operation of seats in compliance with spec. requirements (ie. adjustment, position, design eye, panel and control reach, etc.)		X							X		

* Ejection test covered by subsection 10.6

TABLE 3.5-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 3 of 7)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
III. Restraints											
1. Structural integrity											
a. Flight Crew					X	X		X			
b. Technician Station					X	X		X			
c. Passenger					X	X		X			
2. Functional Operation											
a. Flight Crew		X							X		
b. Technician Station		X							X		
c. Passenger		X							X		
3. Structural integrity of sleep and rest device under anticipated loads and environment					X	X		X			
4. Functional usage, storage, installation of sleep and rest device		X							X		
IV. Mobility Devices											
1. Structural integrity of listed devices used for ingress/egress and mobility during all phases of mission					X	X				X	

TABLE 3.5-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 4 of 7)

Certification Requirement	Certification Method						Level of Assembly				
	Analysis	Simulation	Similarity	Common Usage	Test		Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
					DVT	Qual					
2. Functional operation of listed devices used for ingress/egress and mobility during all phases of mission		X							X		
V. Emergency/Survival											
1. Structural integrity of listed devices											
a. Emergency ground descent device			X			X		X			
b. Sea survival gear			X			X		X			
c. On pad abort					X	X			X		
d. Crash landing evacuation					X	X			X		
e. Decompression provisions					X	X			X		
2. Functional operation of listed devices											
a. Emergency ground descent device		X							X		
b. Sea survival gear		X							X		
c. On pad abort		X							X		
d. Crash Landing evacuation		X							X		
e. Decompression provisions		X							X		

TABLE 3.5-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 5 of 7)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
VI. EVA/Airlock Compartment											
1. Structural integrity of airlock compartment and EVA hatch(es)					X	X				X	
2. Functional operation of airlock compartment and EVA hatch(es)		X								X	
VII. Stowage Compartments											
1. Structural integrity of stowage containters during all anticipated flight contingency and usage load conditions					X	X		X			
2. Functional usage and installation verification of components installed in containers		X						X			
VIII. Hardware Installation											
1. Structural integrity of hardware installation under specified flight loads and environmental conditions											
a. Waste management system					X	X			X		
b. Food management system					X	X			X		
c. All external lights			X		X	X		X			
d. All interior lights			X		X	X		X			
e. ABES quadrant					X	X			X		

TABLE 3.5-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 6 of 7)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
2. Functional and operational compliance to spec. requirements of the following end items											
a. Waste management system		X							X		
b. Food management system		X							X		
c. All exterior lights		X							X		
d. All interior lights		X							X		
e. *ABES quadrant*		X							X		
IX. Materials											
1. Evaluation tests on all non-metallic materials used in cabin to verify compliance with toxicity, flammability, outgassing, etc.	X			X			X				
X. Systems Integration											
1. Structural integrity of support structure for avionics and ECS, CFE and GFE hardware installed in pressure vessel	X							X			
2. Structural integrity of avionics, ECS, CFE, and GFE hardware installed on secondary structure						X			X		
3. Functional operation of installed ECS, CFE, and GFE hardware		X							X		

TABLE 3.5-1. SUBSYSTEM CERTIFICATION REQUIREMENTS
(Sheet 7 of 7)

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
XL. Instrument Panel/Console Assemblies											
1. Structural integrity of instrument panel and console support structure	X							X			
2. Structural integrity of instrument panel assembly electrical assembly end items and console assembly electrical assembly end item					X	X			X		

TABLE 3.5-2 MAJOR COMPONENT LIST
(Sheet 1 of 2)

Component Description	Qty Vehicle	Weight Each, lb
Crew Seat/Couch	2	55.0
Crew Seat/Ejection & Associated Pyro Hardware (Flt Test Only)	2	193.0
Cargo Handler/Technician Seat/Couch	4	50.0
Passenger Seat/Couch	8	50.0
Crew Seat Motor Drive	2	15.0
Crew Restraint Harness	2	7.0
Technician Restraint Harness	4	5.0
Passenger Restraint Harness	8	5.0
Waste Management Unit	1	40.0
Food Management Unit	1	127.0
Portable Fire Extinguisher	2	7.7
Anti-Collision Light	2	5.0
Position Light	3	4.2
Landing/Taxi Light	1	9.0
Tracking Light	1	10.0
Docking Light	2	5.0
EVA Flood Light	2	5.0
Cockpit Flood Light	2	2.0
Cockpit Panel Flood Light	20	0.2

TABLE 3.5-2 MAJOR COMPONENT LIST
(Sheet 2 of 2)

Component Description	Qty Vehicle	Weight Each, lb
Cockpit Panel E/L Light	TBD	TBD
Passenger Flood Light	2	2.0
Passenger Reading Light	8	1.0
Technician Flood Light	4	2.0
Warning Placard	2	0.5
Galley Light	2	2.0
WMS Light	2	2.0
Docking Station Light	2	2.0
Airlock Light	2	2.0
Interconnecting Tunnel Light	2	2.0
Exit Light	3	1.0
Docking Target	1	5.0
ABES Power Quadrant	1	15.0
Emergency Descent Inflatable Slide	1	35.0
Emergency Descent Rope	1	10.0
Sea Survival Gear	1 set	TBD

TABLE 3.5-3 REQUIRED EQUIVALENT UNITS

Hardware Description	Required Equiv. Units
Flight Hardware Per Vehicle	1
Component Devel & Qual Test	2
Integration Tests	1[b]
• Full Mission Simulation Laboratory	1/2[a]
• Integrated Avionics Test Laboratory	1/2[a]
• Flight Controls Hydraulic Test Laboratory	
• Mechanical Systems Test Rigs	
• Propulsion Fluid Breadboards	
• Escape System Test Rig	1/2[a]
Test Articles	
• Propulsion Test Article	
• Structural Test Article	1/2[a]
Spares For Flight Test Program	1
Spares For 445 Flights	2

a. 1/2 means selected items from crew station and passenger accommodations design are required to support these programs.

b. HIFI Mock-up.

TABLE 3.5-4 CREW STATION, EQUIPMENT & PASSENGER ACCOMMODATIONS
BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

Item	Com-mon	Potential Common	Not Common	Remarks
General Philosophy		X		
• Visibility		X		Window frames might be the same
• Attitude Controller/Aero 2 Axis Contr		X		
• Translation Controller/ Throttle		X		If booster uses translation control it could be common
• Instrument Panel Assembly		X		Basic panel structure might be common
• Crew Seats-Production		X		
• Crew Seats-Ejection Type		X		
• CFE, GFE stowage		X		Partial list of equipment might be common
• Avionics, ECS Installation		X		Partial list of equipment might be common
• Restraints		X		
• Internal/External Lighting		X		
• Interior Finish		X		
• Emergency Egress Device		X		
• Hatches		X		
• Waste Management System			X	
• Food Management System			X	
• Secondary Flight Controls		X		

TABLE 3.5-5 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

Item	Requirements
Support Equipment	1. Boresighting equipment for camera and docking target installations 2. Checking fixtures to check installation clearances of electrical component assemblies such as instrument panel 3. GSE devices for ingress/egress on pad and airport
Software	None

TABLE 3.5-6 FACILITY REQUIREMENTS LIST (Sheet 1 of 2)

Title And Description	New	Exist.	Contr.	Govt.
Mockups*				
1. SEB Soft Cabin Mockup		X	X	
2. PDR Soft Cabin Mockup		X	X	
3. CDR Soft/Hard Cabin Mockup		X	X	
4. Hi-Fi Hard Cabin Mockup		X	X	
5. Lighting Mockup		X	X	
Test Articles*				
1. KC-135 Zero Gravity Part Task Test Article		X		X
2. Neutral Buoyancy Full Cabin Test Article		X		X

* For definition see subsection 10.1

TABLE 3.5-6 FACILITY REQUIREMENTS LIST (Sheet 2 of 2)

Title And Description	New	Exist.	Contr.	Govt.
Test Facilities				
1. Lighting lab to support lighting mock-up	X		X	
2. Ejection seat tests (See subsection 10.6)		X		X
3. KC-135 aircraft for zero g simulated tests (See subsection 10.1)		X		X
4. Neutral buoyancy tank for zero g simulated tests (See subsection 10.1)		X		X

3.6 FLIGHT CONTROL MECHANICAL EQUIPMENT

3.6.1 BASELINE SUBSYSTEM DESCRIPTION

The Flight Control Mechanical Equipment consists of:

- Pilot cockpit controls
- Aerodynamic surface actuation system
- Thrust vector control (TVC) actuation system
- Transmission lines

These components are physically located in the H-33 Orbiter as shown in Fig. 3.6-1. This hardware is required to perform the following basic functions:

- Main rocket engine gimbal control
- Main rocket engine and air-breathing engine throttle control
- Attitude and translation control for space flight
- Blended and phased control of ACPS and aerodynamic surfaces during reentry
- Aerodynamic roll, pitch, and yaw control

The cockpit controls consist of a pilot's and a copilot's station, each containing a set of rudder pedals for aerodynamic yaw control, a right-hand attitude controller for aerodynamic pitch and roll control and for three-axis attitude control in space, and a left-hand integrated thrust translation controller for three-axis translation control in space and for throttle control of the main rocket and air-breathing engines. A center console panel provides individual engine trim control of the air-breathing engines. It also provides for individual engine run-up on the ground and for differential thrust of the engines for one-engine-out conditions.

The aerodynamic surface actuation system consists of the elevon drive system and rudder/speed brake drive system. Each system is divided into primary power actuators, which drive the surface, and remotely located secondary control actuators, which mechanically command the primary actuators. The secondary actuator accepts four electronic signals from the RACU and is powered by four hydraulic power supplies.

To provide aerodynamic roll and pitch control, each elevon (one per side) is driven by two, dual tandem, balanced primary power actuators supplied by four independent 3000 psi hydraulic systems. Each pair of elevon actuators is commanded by a single secondary servo actuator via mechanical linkage.

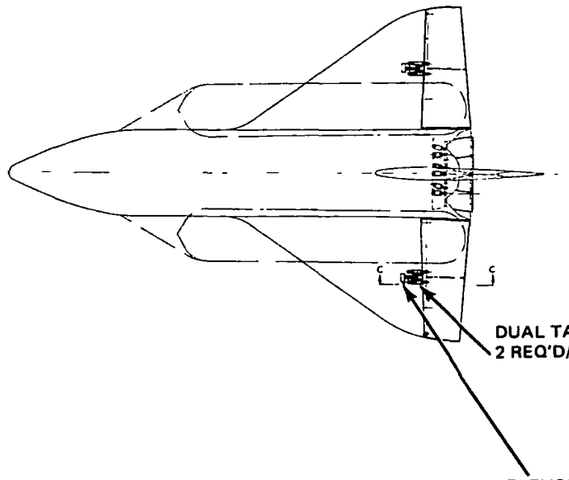
The rudder surface is split spanwise and along the centerline chord (clamshell) into four surfaces to provide:

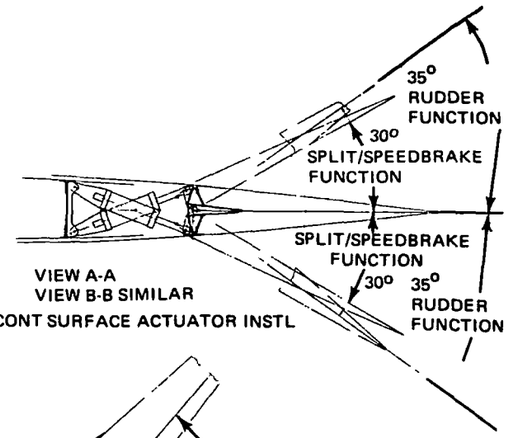
- Yaw control by conventionally moving the four segments in unison
- Subsonic speed control by flaring the lower split segments
- Supersonic directional stability augmentation by flaring both the upper and lower split segments

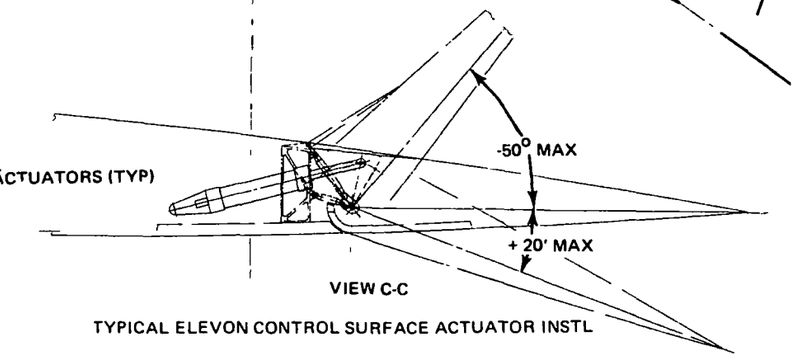
Each segment is driven by one, dual tandem, balanced primary power actuator supplied by two independent 3000 psi hydraulic systems (total of four for the four segments). Each pair of actuators (upper segments and lower segments) is controlled by two remotely located control actuators, which are mechanically mixed. The rudder function is provided by a four channel force summed secondary servo actuator, while the flare function is provided by a two channel, position summed secondary servo actuator.

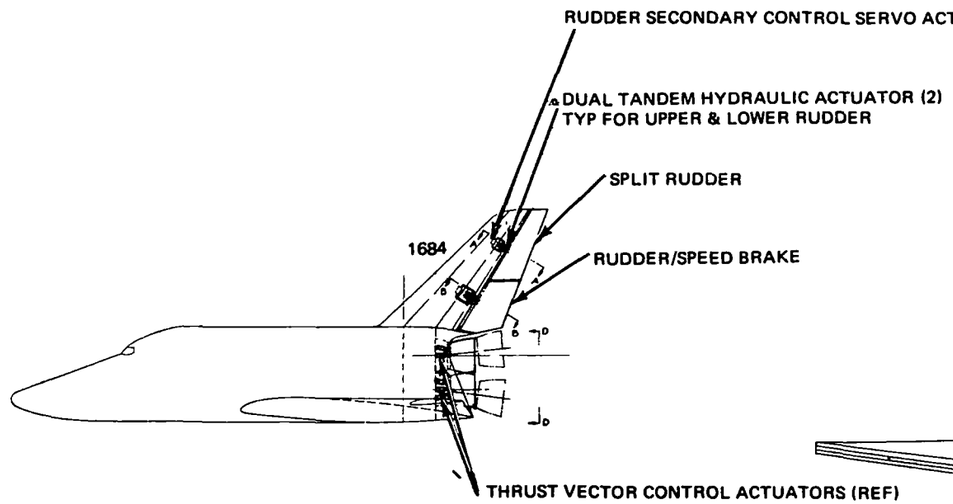
The TVC actuation system provides individual control of each engine gimbal axis to achieve vehicle pitch, roll, and yaw control during ascent. Fully integrated balanced dual tandem actuators are used to drive each gimbal axis. The actuators integrate two hydraulic systems with three electronic signals using conventional detection-correction logic.

Encapsulation techniques are used on all flight control actuators to prevent external leakage.









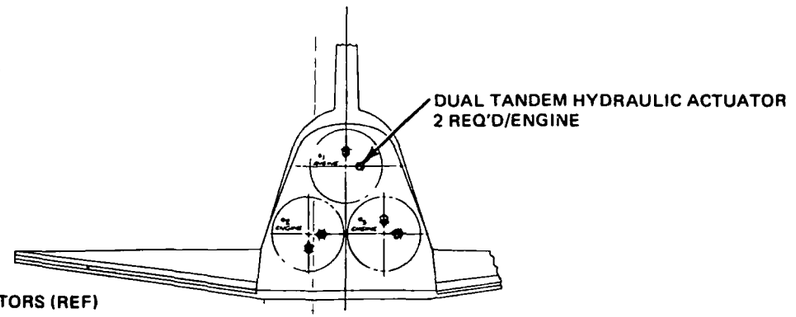


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Fig. 3.6-1 Flight Control Mechanical Equipment Locations

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3.6.2 DEVELOPMENT

The development issues are divided into two categories. The first category concerns extension of the environment as compared to normal aircraft while the second deals with unique functional design features of the equipment. Hydraulic transmission line development issues and overall hydraulic system development issues are discussed in subsection 6.3, Hydraulic Power Subsystem.

3.6.2.1 Environmental Issues

An increase in operating time, temperature, and vibration levels along with space environment requires development work in:

- Flight control bearings to minimize maintenance and replacement
- Primary and secondary actuators to insure meeting the repeated reuse and exposure
- Encapsulation techniques to prevent external leakage (piston rod bellows with return to reservoir)

3.6.2.2 Functional Design Issues

Hand Controllers - the major development issues associated with the pilot controls are:

- Solid state controllers vs currently available Apollo/LM controllers and redesigns to meet specific H-33 requirements
- Integrated vs dedicated translation and throttle controllers to provide x, y, and z axis translation and main rocket engine and air-breathing throttling
- Pencil stick vs conventional Apollo type grip attitude controller to minimize fuel expenditure and maximize control accuracy
- Manual vs automatic switching of the dual mode rotation controller to eliminate transients and provide control harmony

Primary Power Actuators - Development work is required to provide:

- Positive hydraulic lock capability compatible with thermal relief requirements
- Sufficient stiffness to prevent surface flutter while retaining power servo loop stability

- Pressure boost capability, if required, to meet elevon hinge moment requirements during failure conditions

Integrated TVC Actuators - The major development and study issues associated with the TVC actuators are:

- Gimbal excursion studies to substantiate exclusion of centering accumulators and valving
- Optimization of the detection-correction actuator scheme to minimize failure transients

Secondary Control Actuators - The major development issue is the integration of this actuator with the primary power actuators, the four hydraulic systems, and four data bus/RACU signals.

3.6.3 PLAN OF RESOLUTION

Vehicle and subsystem detail requirements will be established early in Phase C/D. After analysis and trade studies, alternate approaches will be pursued where necessary to ensure a success path. The specific technical expertise and assistance of qualified suppliers will be sought to assist in candidate approach selection and in the following development phases. Breadboard, design feasibility testing and design verification testing in simulated environments will be used as the level of risk dictates. Qualification test plan reviews will aid in determining the extent to which vibration and thermal vacuum testing will be required to demonstrate adequacy of the selected designs. Thrust vector control actuators will be tested in conjunction with the main engines in static test firing to determine their capability to withstand engine side loads and vibration. All flight control actuator prototypes will be structurally loaded to determine stiffness and transient performance. The prototype hardware will be incorporated into the Flight Controls Hydraulic Test Laboratory (FCHTL) to determine electrical and mechanical interface compatibility. The LM Data Reduction Center will be used in the design feasability and design verification test phases.

For the orbiter baseline it is assumed that all flight control mechanical equipment will be certified by full qualification testing at the assembly level to determine endurance capabilities and environmental design limits. Flight control actuators will be tested in the FCHTL to certify system performance. Hand controllers will be incorporated into a

moving base simulator where human factors and performance studies will be conducted. All flight control equipment and lines will be installed in the equipment lines mockup to assure that the hardware meets fit and maintainability requirements. Integrated vehicle ground test and check out will be used to certify the end-to-end system for flight as described in subsection 10.6, Integrated System Test and Simulation.

3.6.4 FLIGHT CONTROLS EQUIPMENT DATA

Flight controls equipment data is given in Tables 3.6-1 through 3.6-6.

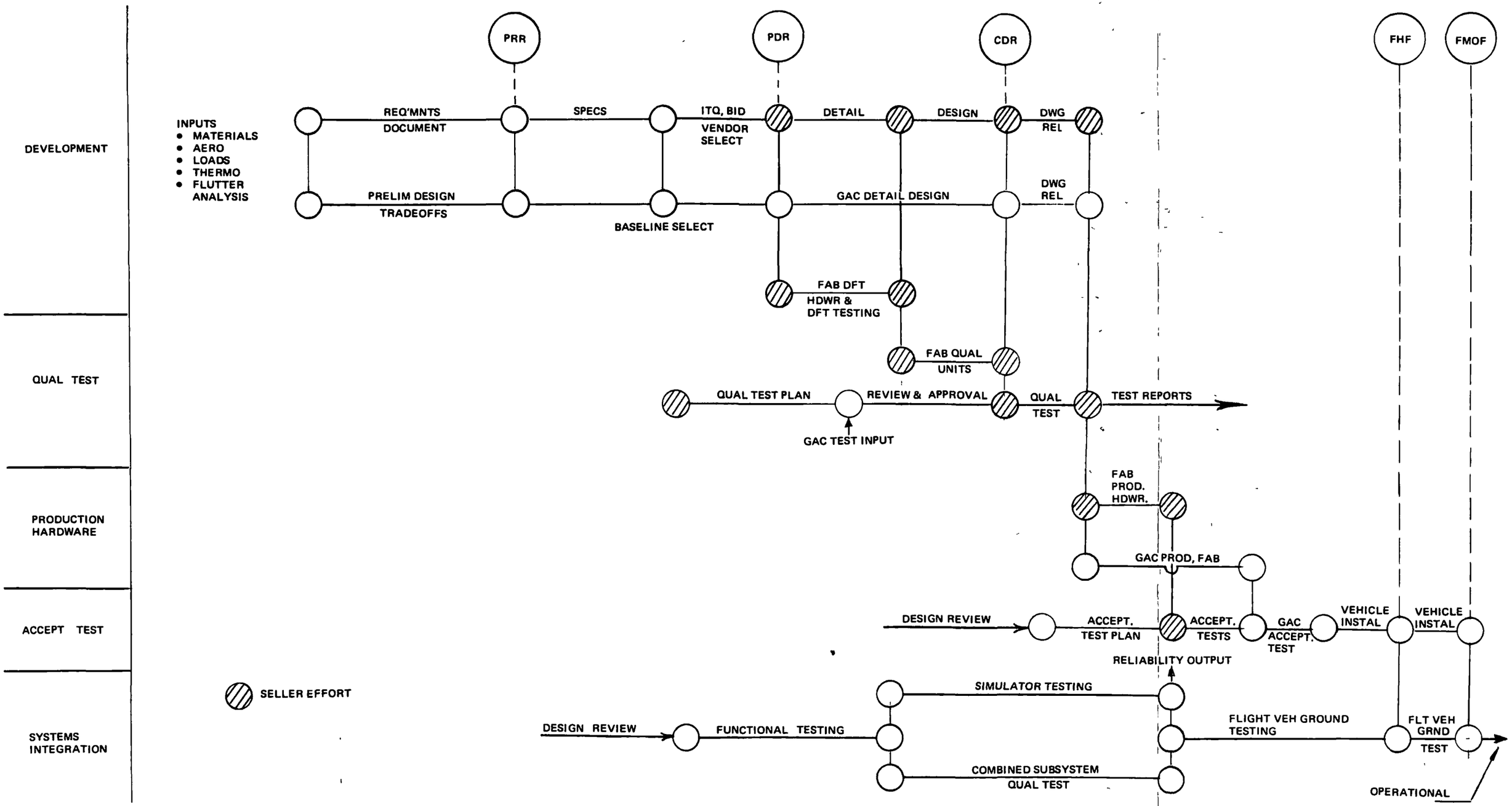

Fig. 3.6-2 Flight Control Mechanical Equip. Logic Network

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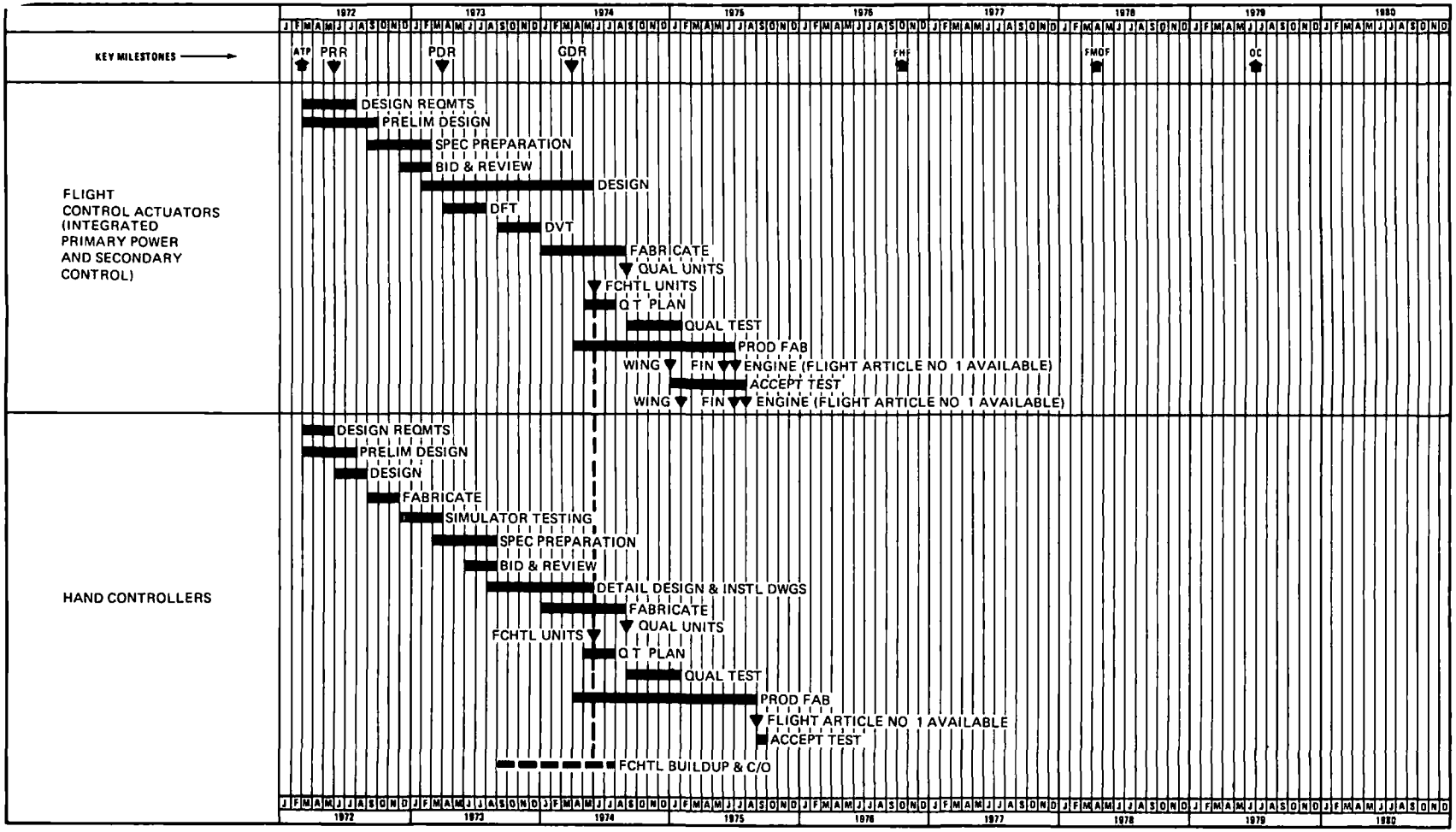

Fig. 3.6-3 Flight Control Mechanical Equipment Schedule

TABLE 3.6-1 FLIGHT CONTROLS SUBSYSTEM CERTIFICATION REQUIREMENTS (Sheet 1 of 2)

Certification Requirement	Certification Method						Level of Assembly				
	Analysis	Simulation	Similarity	Common Usage	Test		Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
					DVT	QUAL					
Flight Control Secondary Actuators											
• Sensitivity	X					X		X			
• •Response rates	X				X			X			
• Structural stiffness	X				X			X			
• Leakage	X					X		X			
• Thermal vacuum (High & Low Temp)	X				X	X		X			
• Vibration	X				X	X		X			
• Shock	X				X	X		X			
• Design limit environments	X					X		X			
• Endurance testing	X					X		X			
• System Compatability	X									X	
Rudder Pedals											
• Structural integrity	X				X			X			
• Vibration	X				X	X		X			
• Thermal vacuum (High & Low Temp)	X				X	X		X			
• Design limit testing	X					X		X			
• Endurance testing	X					X		X			
• System compatability	X	X								X	

TABLE 3.6-1 FLIGHT CONTROLS SUBSYSTEM
CERTIFICATION REQUIREMENTS (Sheet 2 of 2)

Certification Requirement	Certification Method						Level of Assembly				
	Analysis	Simulation	Similarity	Common Usage	Test		Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
					DVT	QUAL					
ACA & TTCA Hand Controllers											
• Thermal vacuum (High & Low Temp)	X				X	X		X			
• Vibration	X				X	X		X			
• Shock	X				X	X		X			
• Human factor testing (feel, etc.)	X	X			X					X	
• Design limit environments	X					X		X			
• Endurance testing	X					X		X			
• System compatability	X	X								X	
Flight Control Actuators (Primary and Integrated)											
• Response Rates	X				X	X		X			
• Load capability	X					X		X			
• Sensitivity	X				X	X		X			
• Stiffness	X				X	X		X			
• Leakage	X					X		X			
• Thermal Vacuum (High & Low Temp.)	X				X	X		X			
• Endurance testing	X					X		X			
• Shock	X					X		X			
• Vibration	X				X	X		X			
• System capability	X									X	

TABLE 3.6-2 FLIGHT CONTROLS MAJOR COMPONENT LIST

No.	Description	Qty/ Vehicle
1	Two Channel Secondary F. C. Actuator	2
2	Attitude Control Assembly (ACA)	2
3	TVC Integrated F. C. Actuator	6
4	Thrust/Translation Control Assembly (TTCA)	2
5	Elevon Power F. C. Actuator	4
6	Four Channel Secondary F. C. Actuator	4
7	Rudder/Speed Brake Power F. C. Actuator	4
8	Rudder Pedal Assembly	2

TABLE 3.6-3 FLIGHT CONTROLS REQUIRED UNITS

Description	Required Units							
	2-Channel Sec. FC Act.	TVC Integrated FC Act	Elevon Power FC Act	ACA Controler	TTCA Controller	4-Channel Sec. FC Act.	Rudder Pedal Assy	Rudder/Speed Brake FC Act
Flight Hardware Per Vehicle	2	6	4	2	2	4	2	4
Component Development & Qual Test	2	4	3	2	2	4	2	3
Integration Tests								
• Full Mission Simulation Lab				4	4			
• Integrated Avionics Test Lab				2	2			
• Flight Controls Hydraulic Test Lab	2	6	4			4		4
• Mechanical Systems Test Rigs	2	2	2			2		2
• Propulsion Fluid Breadboards								
• Escape System Test Rig								
Test Articles								
• Propulsion Test Article		6						
• Structural Test Article	2	6	4	2	2	4	2	4
Spares For Flight Test Program	2	6	4	2	2	4	2	4
Spares For 445 Flights (Total Spares)	4	12	8	4	4	8	4	8

TABLE 3.6-4 FLIGHT CONTROLS BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

Item	Common	Potential Common	Not Common
TVC Integrated FC Actuator		X	
ACA Hand Controller		X	
Elevon Power FC Actuator			X
TTCA Hand Controller		X	X
2 Channel Secondary FC Actuator			X
4 Channel Secondary FC Actuator	X		
Rudder Pedal Assy		X	
Rudder/Speed Brake Power FC actuator			X

TABLE 3.6-5 FLIGHT CONTROLS SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

Item	Requirements
Support Equipment	• Portable checkout box that will mate with both ACA & TTCA connectors and be capable of functionally testing controllers without removal from orbiter vehicle • Hydraulic actuator overhaul bench with hydraulic pressurization and metering system • Actuator handling equipment required to install actuators in the orbiter • Bench test equipment for hydraulic actuators
Software	Programs to implement the following: • Simulated aeroloads on elevons, rudder, and speed brakes resulting in loads on FC actuators for a typical mission profile • Programs to determine thermal and vibrational environments that thrust vector control actuators will see during a nominal mission • Programs to determine off-nominal (worst case postulating one or more failures) values for the above areas

TABLE 3.6-6 FLIGHT CONTROLS FACILITY REQUIREMENTS LIST

Facility	New	Exist'g	Contr	Gov
• Flight Controls Hydraulic Test Stand (Refer to subsection 10.5)	X		X	
• Moving Base Simulator (Some Modification Req'd)		X	X	
• Static & Fatigue Test Fixtures (Refer to subsection 10.3)	X		X	
• Hydraulic Subsystem Test Facility Hi-Lo Temp. Chamber (15 ft x 5 ft x 5 ft, 440v, 220v, 28vdc, H_2O, N_2, Drain)	X		X	

3.7 RECOVERY SUBSYSTEM

The recovery subsystem is composed of three major installations: the nose landing gear, the main landing gear, and the deceleration parachute arranged as shown in Fig. 3.7-1.

The function of the recovery subsystem landing gear is to provide the orbiter vehicle with the means to perform all modes of ground operations; e.g., taxi, turning, towing, brake, park and provide a stable high speed platform for takeoff and landing. The deceleration parachute is provided to augment aerodynamic and main wheel braking.

The nose and main gear assemblies consist of the following similar components: shock strut, trunnion fittings, drag brace, dual wheels and tires, uplock, downlock, gear actuation and indication systems, and door actuation and locking mechanism. Additionally the nose gear incorporates steering and damping mechanism with skid-controlled brakes provided on the main gear.

The deceleration parachute system consists of two main deceleration chutes, two pilot chutes and chute deployment, locking and jettisoning mechanisms.

Both main and nose landing gear assemblies will be hydraulically operated for normal retraction and extension. For emergency extension conditions the gear shall free fall from the orbiter, assisted by the air stream and backed up by pneumatic pressure. The brakes will be hydraulically operated and electrically skid controlled. The steering mechanism is hydraulically operated and electrically controlled.

The engineering development techniques will be the same as that for a high-performance airplane with the following exceptions and/or additions:

- Complete screening and testing of materials to meet the space environment during orbiting and the high temperature requirements during reentry; especially seals, lubricants, tires and fluids

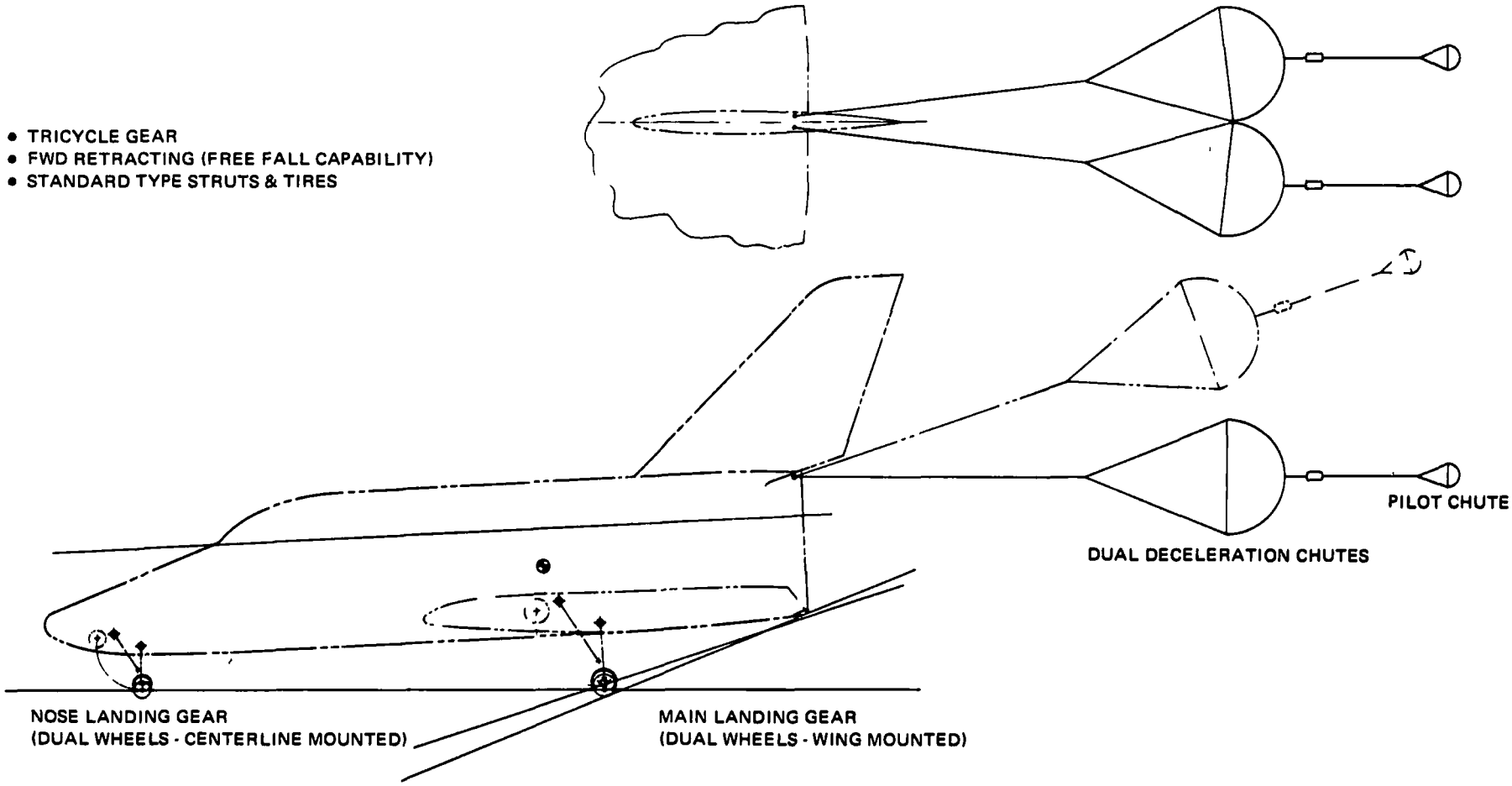

Fig. 3.7-1 Recovery Sub-System Arrangement

- An assessment of design requirements to ensure that the parameters are consistent with the mission profile
- Review and development testing of new materials and designs to determine the best construction for lightweight design; such as carbon composites for brakes, carbon or boron filament for landing gear structural elements
- Use of experimental structural analysis such as photostress to eliminate stress concentrations and remove excess material
- Complete operational checkout including critical loading conditions on the full-size, functionally-compliant Flight Controls Hydraulic Test Stand. All systems will be available to verify the normal and backup modes for gear extension

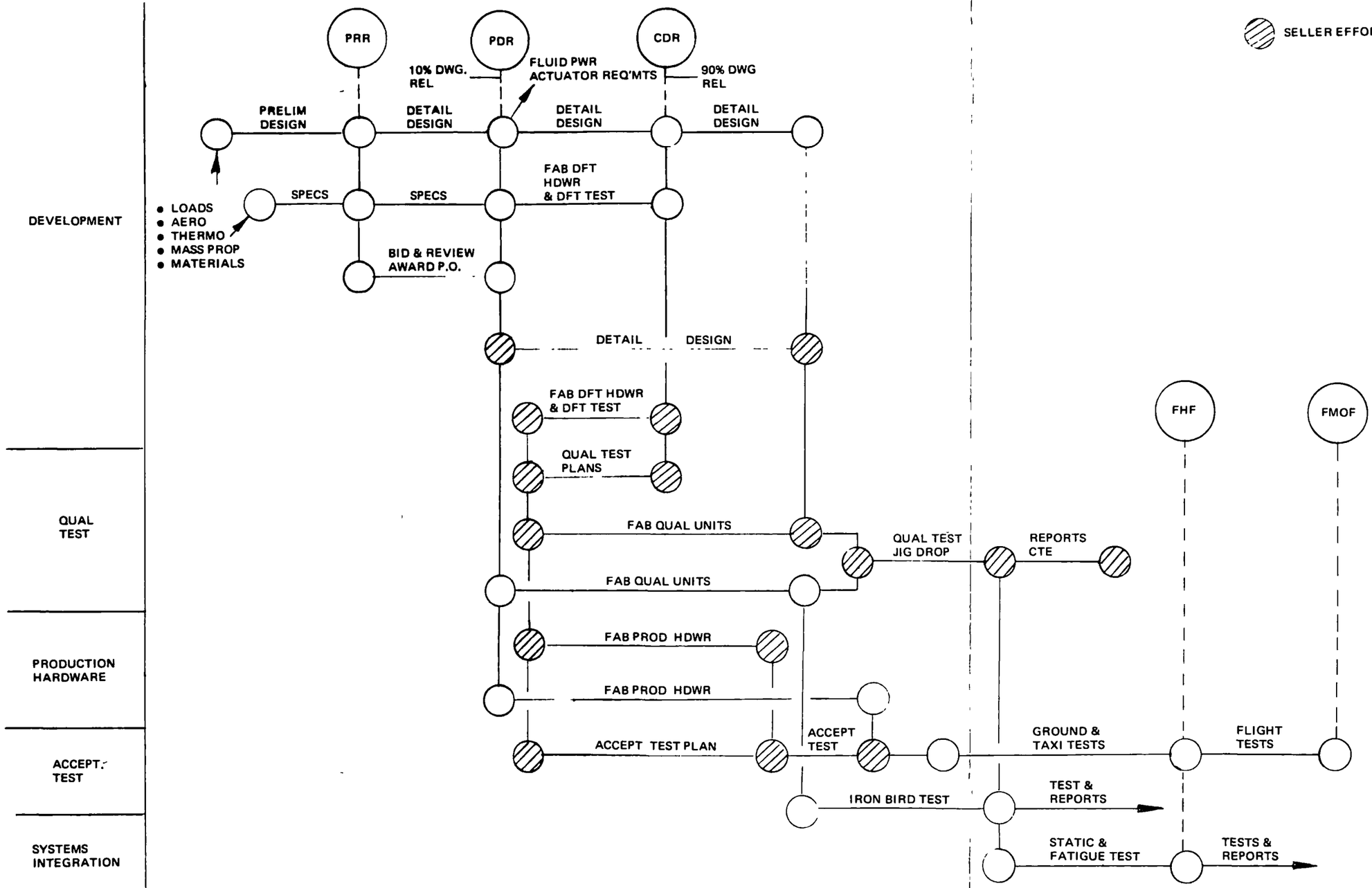

Fig. 3.7-2 Recovery (Landing Gear & Deceleration Chute) Logic Network

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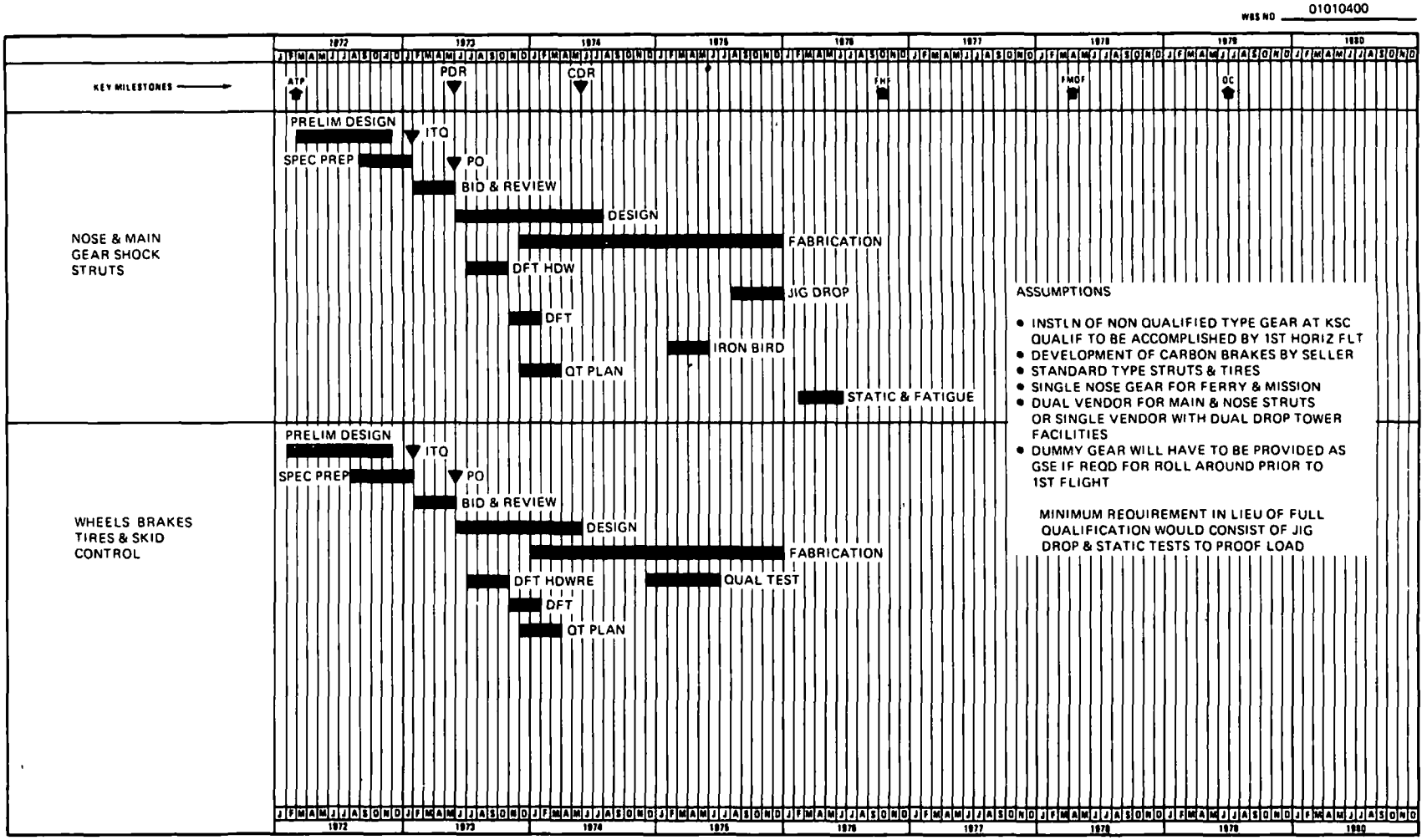

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Fig. 3.7-3 Recovery Subsystem Schedule (Sheet 1 of 3)

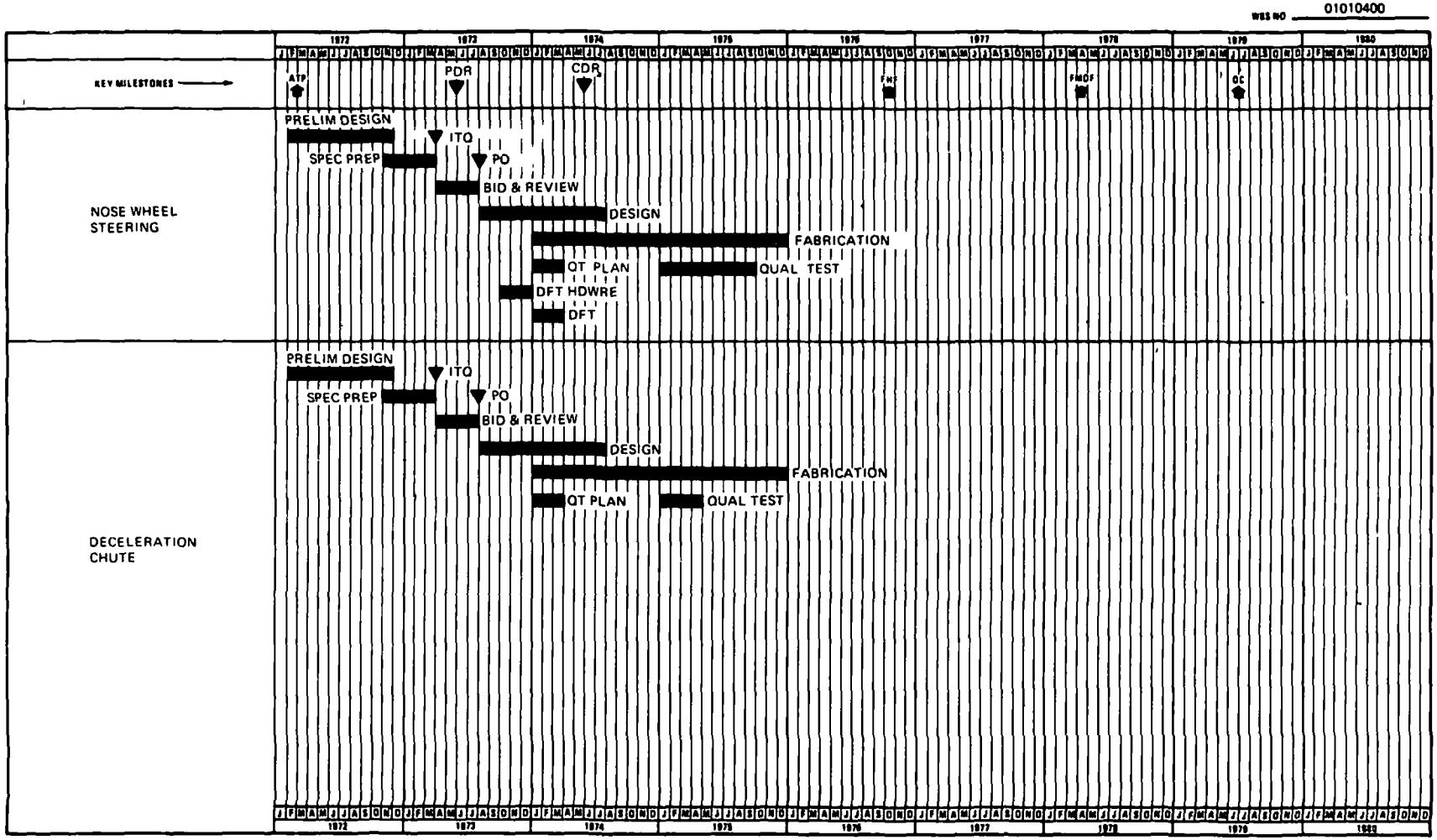

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Fig. 3.7-3 Recovery Subsystem Schedule (Sheet 2 of 3)

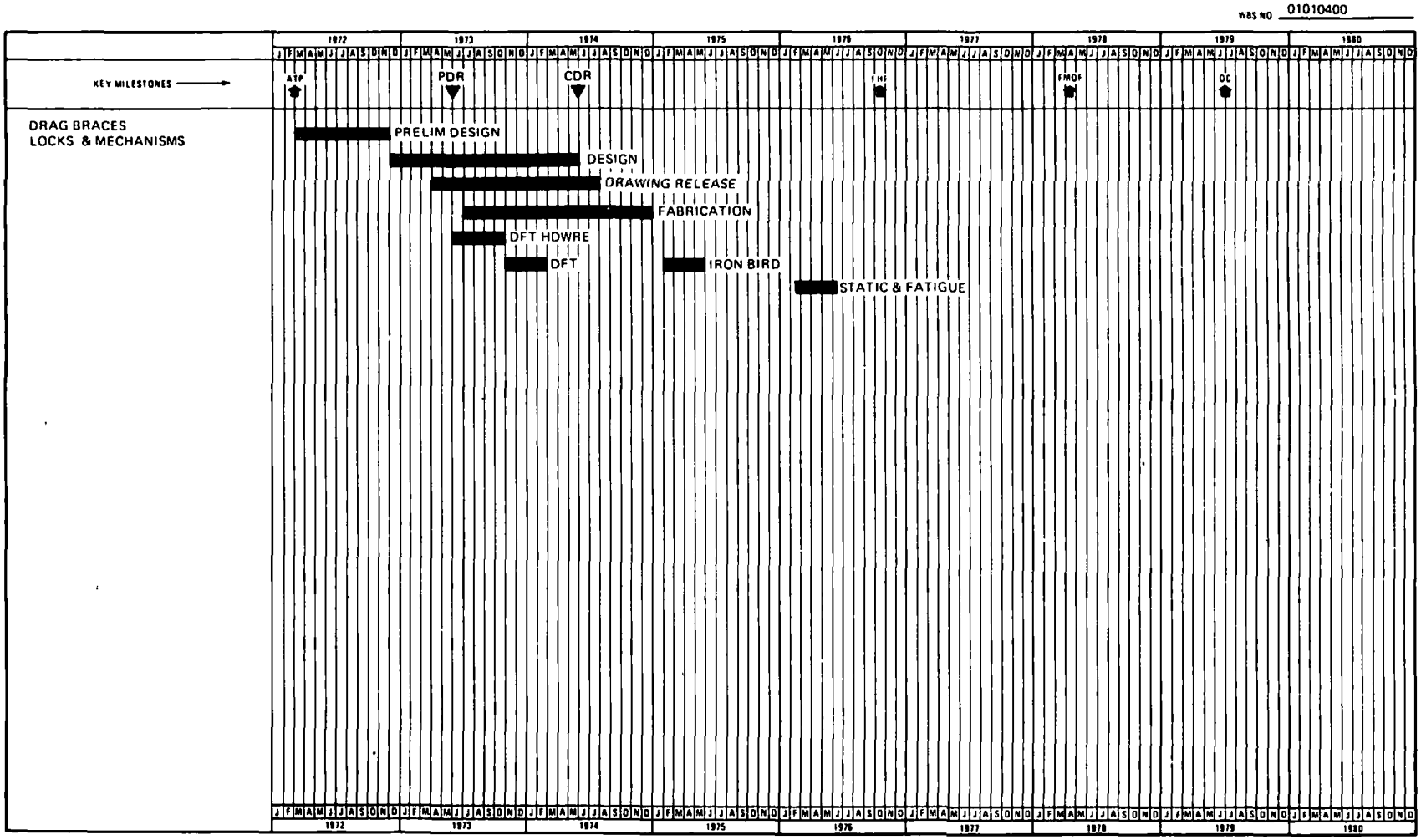

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Fig. 3.7-3 Recovery Subsystem Schedule (Sheet 3 of 3)

TABLE 3.7-1. SUBSYSTEM CERTIFICATION REQUIREMENTS

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
Verify the:											
1. Functional operation of Main Landing Gear, Nose Landing Gear including electrical & hydraulic equipment, doors, actuators, uplocks, downlocks for extension & retraction under aerodynamic & inertia loads. Demonstrate wear life, fatigue life & system reliability. Also to demonstrate emergency modes of gear extension.	X				X					X	
2. Structural & functional adequacy of nose wheel steering/damping system(*)	X					X		X			
3. Shock strut energy absorption characteristics (jig drop)(*)	X					X		X			
4. Structural adequacy of landing gear for ultimate & repeated loads						X				X	
5. Structural & functional adequacy of wheel & brake(*)						X	X				
6. Structural & functional adequacy of skid control system(*)	X					X		X			
7. Structural & functional adequacy of tires(*)	X					X	X				
8. Structural & functional adequacy of deceleration chute mechanism (restraining & release)(*)					X	X		X			
9. Functional & structural adequacy of deceleration chute						X	X				
10. Functional performance of deceleration system					X						X

* Exposure to mission environmental profile included in these tests

TABLE 3.7-2 MAJOR COMPONENT LIST

Component Description	Qty/Vehicle	Weight Each, lb	Size Each
MLG Shock Strut	2	1728	--
MLG Drag Brace	2	456	--
MLG Wheel	4	170	
MLG Tire	4	177	49 x 17
MLG Wheel Brake	4	190	
NLG Shock Strut	1	516	--
NLG Drag Brace	1	140	--
NLG Wheel	2	48	
NLG Tire	2	59	34 x 9.9
NLG Steering-Shimmy Damper	1	50	--
Deceleration Chute	2	155	30' dia

TABLE 3.7-3 REQUIRED EQUIVALENT UNITS

Hardware Description	Required Equiv. Units								
	MLG Assy	NLG Assy	Wheels	Tires	Brakes	Skid Control	Steering	Decel. Chute	Chute Mech.
Flight Hardware Per Vehicle	2	1	6	6	4	1	1	2	1
Component Devel & Qual Test	1	1	4	12	2	2	2	4	
Integration Tests									
• Full Mission Simulation Lab									
• Integrated Avionics Test Lab									
• Flight Controls Hydraulic Test Lab	2	1	6	6	4	1	1		1
• Mechanical Systems Test Rigs									
• Propulsion Fluid Breadboards									
• Escape System Test Rig									
Test Articles									
• Propulsion Test Article									
• Structural Test Article	1	1					1		1
Spares for Flight Test Program	2	1	6	24	40	1	1	40	1
Spares for 445 Flights	2	1	18	2940	100	1	1	196	1

TABLE 3.7-4. BOOSTER/ORBITER COMMONALITY CANDIDATES LIST

Item	Common	Potential Common	Not Common	Remarks
Equipment				
Wheels		X		Commonality resolution is dependent upon the specific design problems in each area
Tires		X		
Skid Control System		X		
Software (computer programs)				
Landing deceleration performance		X		
Flotation		X		
Metering Pin Design		X		

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TABLE 3.7-5. SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

Item	Requirements
Support Equipment	Nose and main gear jacks for wheel, tire and brake changing Vehicle jacks for gear cycling Nose and main gear ground safety locks Hydraulic and pneumatic strut servicing units Hydraulic power unit Electrical power unit Load application devices "Dummy Gear" for roll-around Gear assembly and disassembly tools
Software	None

TABLE 3.7-6. FACILITY REQUIREMENTS LIST

Title and Description	New	Exist.	Contr.	Government
Test Facilities:				
Static and Fatigue Test Fixtures. (See subsection 10.2)	X		X	
Landing Gear Functional Test See subsection 10.6	X		X	
Note: All other testing to be accomplished at existing Seller facilities				

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3.8 PAYLOAD DEPLOYMENT/RETRIEVAL AND DOCKING SUBSYSTEM

This subsystem includes the orbiter mechanism/systems/subsystems necessary to support, deploy, retrieve, stow, and service payloads, and to open and close the cargo bay doors.

A large number of payloads having an extensive range of dissimilar requirements have been identified. The key to shuttle usefulness is to provide a design having sufficient flexibility to accommodate these demands without the necessity of tailoring to individual modules. Since many modules are being developed simultaneously at widely separated locations, it is necessary to decouple their development from shuttle development and operations. Experiment/spacecraft integration as practiced up to Apollo will no longer be feasible or desirable. A prime goal, and a high program risk is to qualify payload modules and ensure compatibility with the shuttle prior to delivery or installation.

To attain this goal, interfaces are established and controlled: the instrument of control is the ICD. The task of payload integration, (see Section 8) is to establish interface requirements, the level of shuttle capability required, ancillary equipment, operational procedures, mission support, and crew participation. These requirements are implemented in the design of payload handling and support mechanisms.

3.8.1 PAYLOAD CLASSIFICATION

For purposes of physical support, deployment and retrieval, payloads are divided into three categories as follows:

(a) Those that remain physically attached to the shuttle for the duration of mission. Functionally, these may vary from completely independent to fully dependent on the shuttle for support

(b) Those that are separated and never retrieved

(c) Those that are separated and subsequently captured either for service or return to earth

3.8.1.1 Baseline Deployment/Retrieval Mechanism

A pallet containing a matrix of physical support points and electric/fluid connections is the support and deployment device for payloads (a) and (b) above. The pallet shown in Fig. 3.8-1 has a simple interface with the shuttle, permitting quick turnaround time, and since it is separable, the payload modules and ancillary equipment are mounted and tested at remote facilities. The pallet is deployable and can provide a platform for launching non-retrievable modules. For those payload modules requiring manned attendance, a flexible tunnel provides shirtsleeve access from the crew quarters.

3.8.1.2 Docking

For retrieval of free-flying modules, docking is employed. Docking is accomplished through the payload module, thereby locating docking ports and mechanisms in the payload bay. The docking system along with an aft payload support (adjustable for individual payload length) is also used as a basic support for single modules in attached condition, either deployed or undeployed. Figure 3.8-2 illustrates the concept.

One alternative device under consideration is the manipulator which promises greater operational flexibility than the docking system. Parallel studies of both systems are conducted for approximately one year during preliminary design and then final selection is made. This plan does not reflect manipulator development. The neuter docking mechanism described here permits any two spacecraft to dock and provides for pressurized transfer through a 5 ft diameter clear opening.

3.8.2 ORBITER/PAYLOAD COMPATIBILITY

The following means are employed to establish physical and functional compatibility:

- ICD's
- Design reviews
- A detailed scale model of the orbiter payload bay and deployment mechanisms is used with scale models of the payload to provide visual aid to NASA and the payload designer as a means to avoid physical and functional incompatibilities
- Subsystem qualification

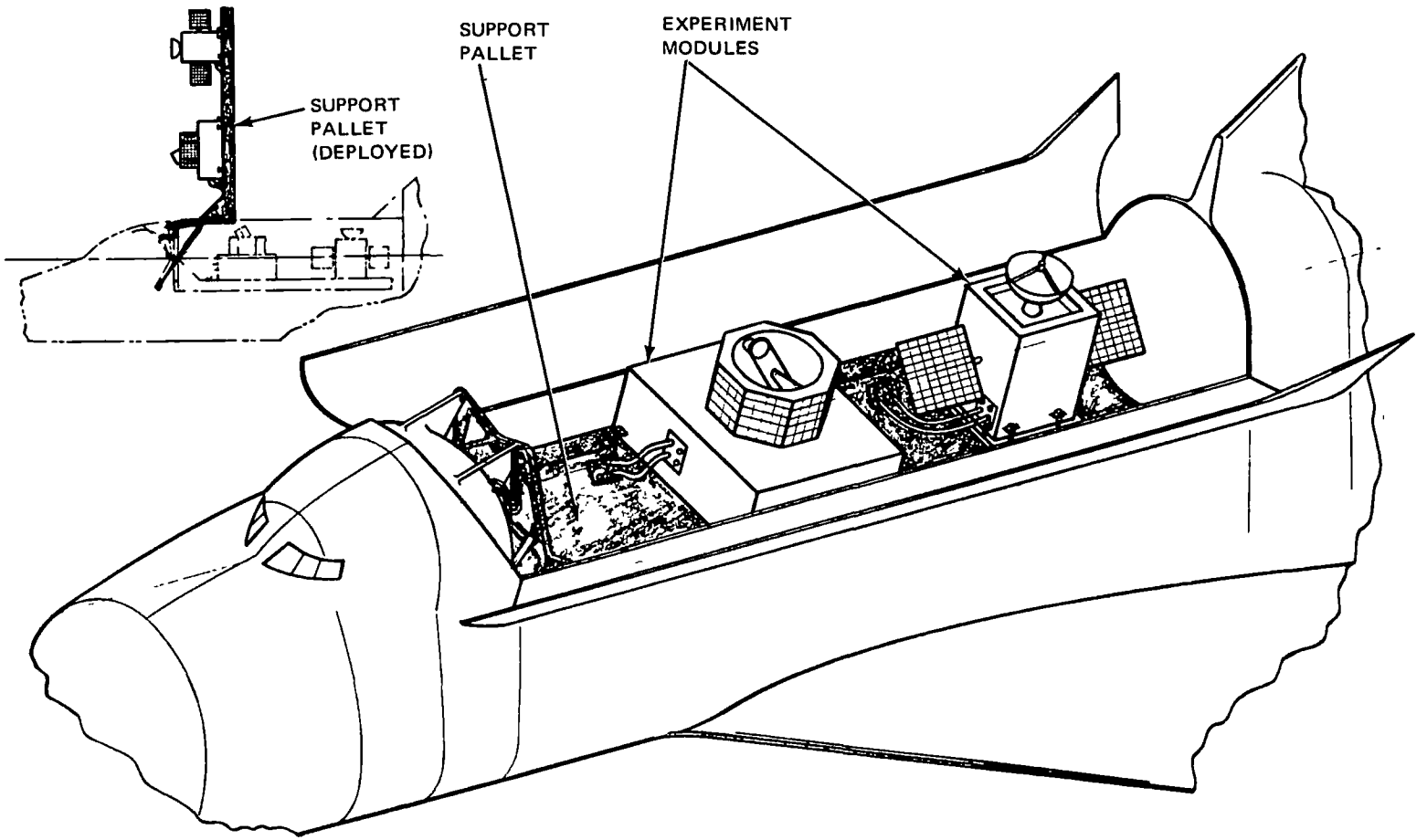

Fig. 3.8-1 Payload Support Pallet

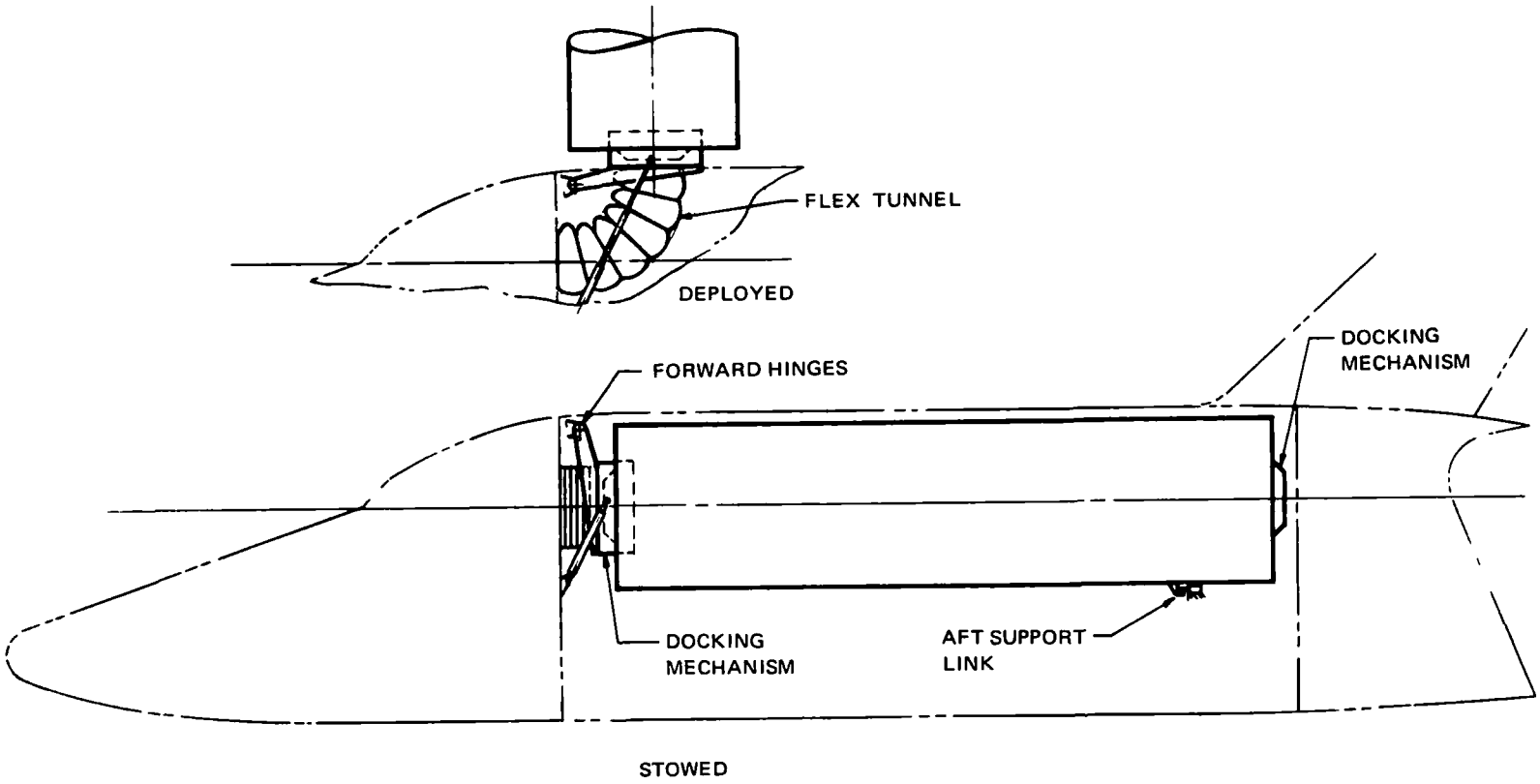

Fig. 3.8-2 Payload Support/Development

- Structural/dynamic tests
- Thermal vacuum tests
- Hard interface tooling is used to assure absolute fit with physical interfaces
- Functional test stands are used to duplicate orbiter supply functions (i.e., power, cooling, purging, venting, etc.)
- Full-scale soft mockups are used at Grumman on the structural systems lines runs mockup to develop special harnesses, lighting, etc. for payloads that do not meet standard interface requirements

A full-scale flight weight test article is used to simulate the payload bay, doors, and deployment mechanisms. This test article is used for final check of physical and functional interfaces of all flight payloads and to qualify payloads prior to installation in the flight vehicle. It provides the necessary capability of decoupling experiment integration from orbiter operations. The test article is the responsibility of the NASA/payload integrator and its cost and development are add-on contracts to the orbiter manufacture, as are the hard interface matching tools.

3.8.3 PAYLOAD PALLET

The payload pallet is a structural assembly containing physical and functional payload interfaces, and has a simple structurally-determinant connection to the orbiter. Fluid and electrical power supplies to alternative payload connections in the pallet are run in parallel circuits to minimize interaction between separate payloads. Deployment is provided by using the same geometry, hinge points, and linear actuators developed for the deployable docking mechanism.

Major functional and design concerns of the pallet are:

- Structural integrity
- Dynamic behavior, deployed and undeployed, with a large combination of masses and mass distributions
- Thermal distortions

- Thermal conductivity
- Isolation from orbiter structural/thermal distortion
- Alignment with orbiter stabilization control system
- Compatibility with orbiter-supplied ECS/EPS

DFT, DVT, and qualification tests are performed on appropriate components, subassemblies, and the pallet assembly to verify the following:

- Pallet structure
- Payload interface structural connections
- Orbiter/pallet connections
- Electrical/fluid circuits and circuit isolation
- EMI, RFI
- Grounding
- Dynamic and acoustical vibration characteristics
- Thermal/vacuum distortions

Combined subsystem tests will be performed on the installed pallet to verify compatibility with the orbiter as follows:

- Fluid/electrical interfaces
- Dynamic/acoustical vibration responses
- Thermal compatibility
- Deployment system and clearance
- Aft attachment re-engagement after deploying

Flight tests will initially verify the capability of the stowed (undeployed) pallet with later flights verifying deployed characteristics, and the ability to stow after deployment.

3.8.4 DOCKING MECHANISM

The docking mechanism is an assembly containing a capture device, shock absorbers, pressure tunnel and seals, and docking latches, all mounted on a deployable structural platform hinged to the cabin. A flexible tunnel permits shirtsleeve transfer from the cabin to an attached (docked) pressurized payload module.

3.8.4.1 Analyses and Simulations

It is not feasible to verify docking in a 1 g environment, or by underwater 0 g simulations; therefore a combination of dynamic analysis, scale simulations, qualification of components, subassemblies and practical combined subsystems, and structural tests will be employed. Dynamic simulation programs of two body motions will establish the ability of the mechanism to make initial contact and absorb shock. The analysis (made both by Grumman and NASA/MSC in parametric form to cover the range of masses and inertias of all the spacecraft in the program) will yield data on the shock strut characteristics for hardware design.

Preliminary DFT hardware complementing the analysis includes two major items:

- A complete full scale set of the capture and shock attenuator devices used in 2-dimensional air bearing tests
- An accurate 1/3 scale working model of the capture and attenuation mechanism delivered to NASA/MSC for use on their 20-degree-of-freedom docking simulator

The air bearing test (ground effects machine) confirms the ability of the mechanism to capture under the range of specification contact conditions. The mechanisms are mounted on large masses (approximately 5000 lb) in a manner to simulate contact geometry conditions. Initial contact and capture loads are expected to be very low; therefore, it is not necessary to duplicate masses and inertias of the spacecraft to demonstrate this phase of docking.

The MSC docking simulator verifies initial contact information and supplies the mechanism loads for post-contact stabilization and pull down to final docked position. An

analysis program performed at both Grumman and MSC integrates the approach sensors and automatic flight modes. Full mission simulations verify manual docking capability and docking backup modes.

Tests are performed to verify docking subsystems in these areas:

- Final guidance and approach within specification tolerances
- Ability to capture and attenuate motion and stabilize
- Ability to hard dock and survive structural loads
- Ability to provide pressurized passage from orbiter to another module
- Ability to survive all environments

These tests are performed on the combined docking subsystems:

- Guidance sensor and target alignment and guidance sensor system ability to provide appropriate signals to G & C subsystems
- Component and subassembly qualification
- Structural integrity
- Systems integration (tests on both combined subsystem and flight vehicle level)
- Thermal vacuum tests
- Structural dynamics/shock

3.8.4.2 Docking Hardware and System Qualification

Qualification is performed on a component and subassembly level, both at Grumman and vendor facilities. Structural and dynamic tests are on full assemblies mounted on a fixture simulating shuttle backup structure. Combined subsystems (including docking sensors and full electrical circuits) are demonstrated in ambient and thermal vacuum environments. Pressure sealing and mating of the docking interfaces is verified in the thermal vacuum chamber.

3.8.4.3 Flight Test

Since actual docking can only be demonstrated in space, a progressively complex series of operations occur early in the flight test program. The test sequence involves first opening the payload bay doors, then progresses to deploying docking mechanism, releasing a free flying payload, approaching a target, and finally retrieving a free flying module. A constant updating of the ICD accompanies the development program.

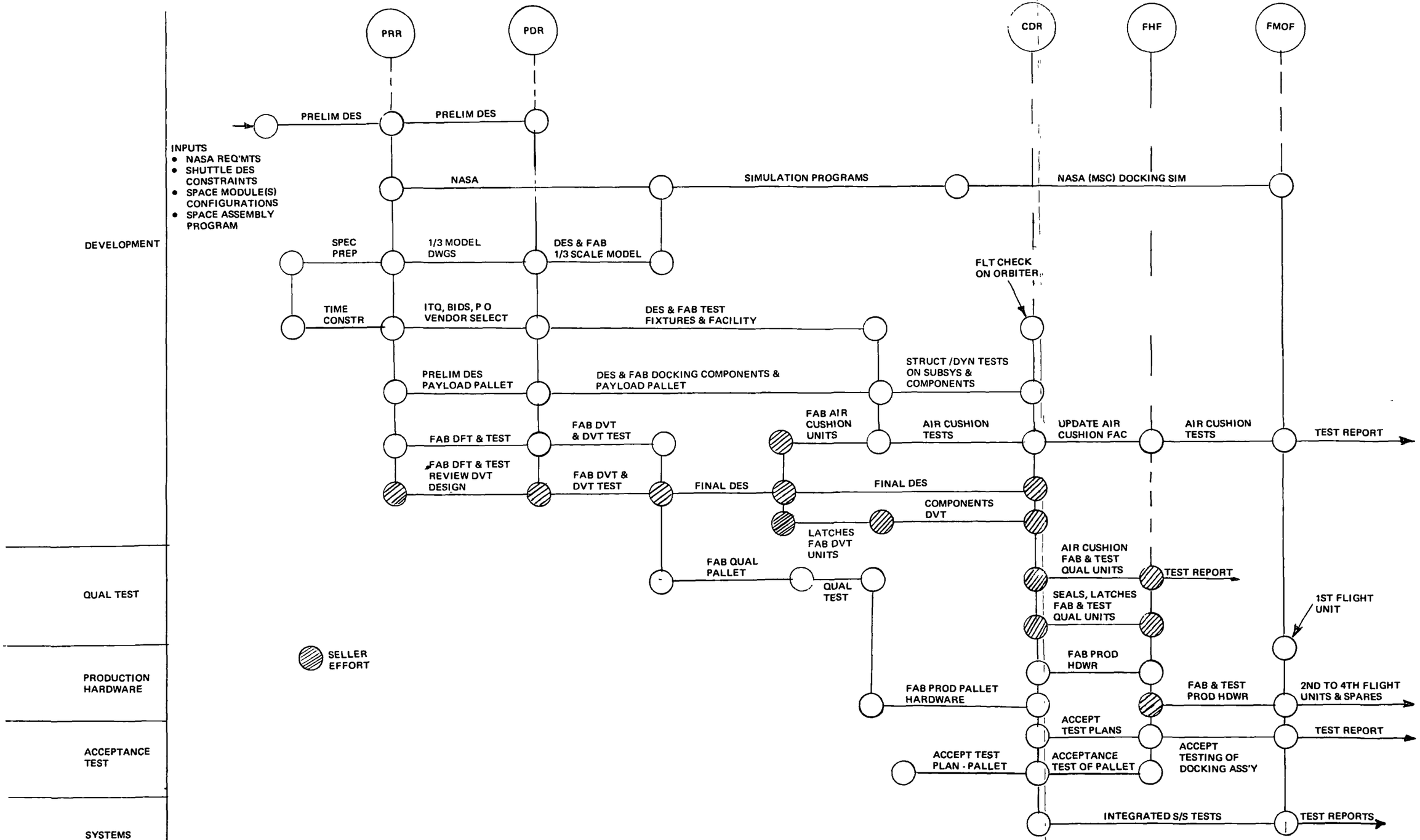

Fig. 3.8-3 Payload Development Logic Network

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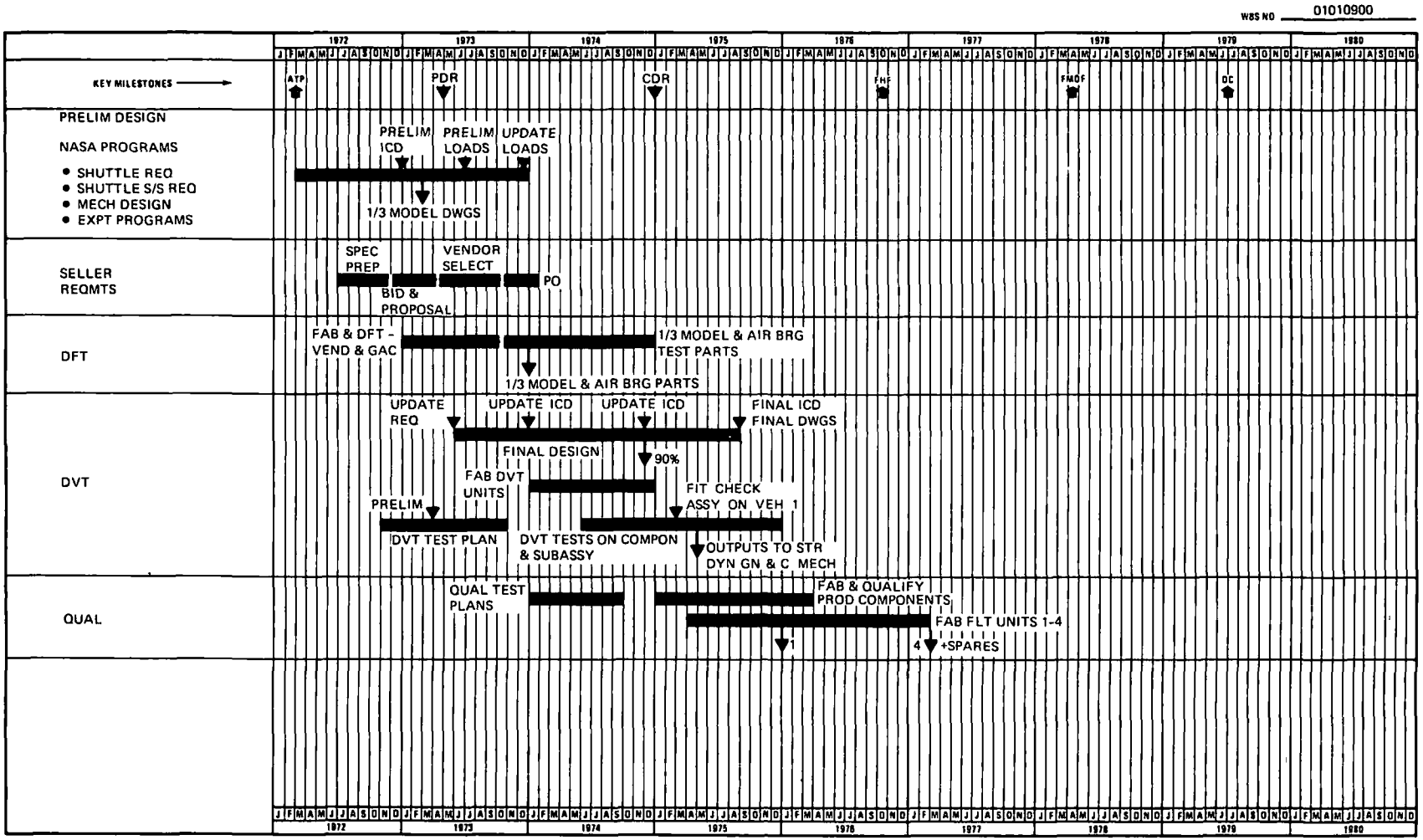

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Fig. 3.8-4 Payload Deployment Schedule (Sheet 1 of 3)

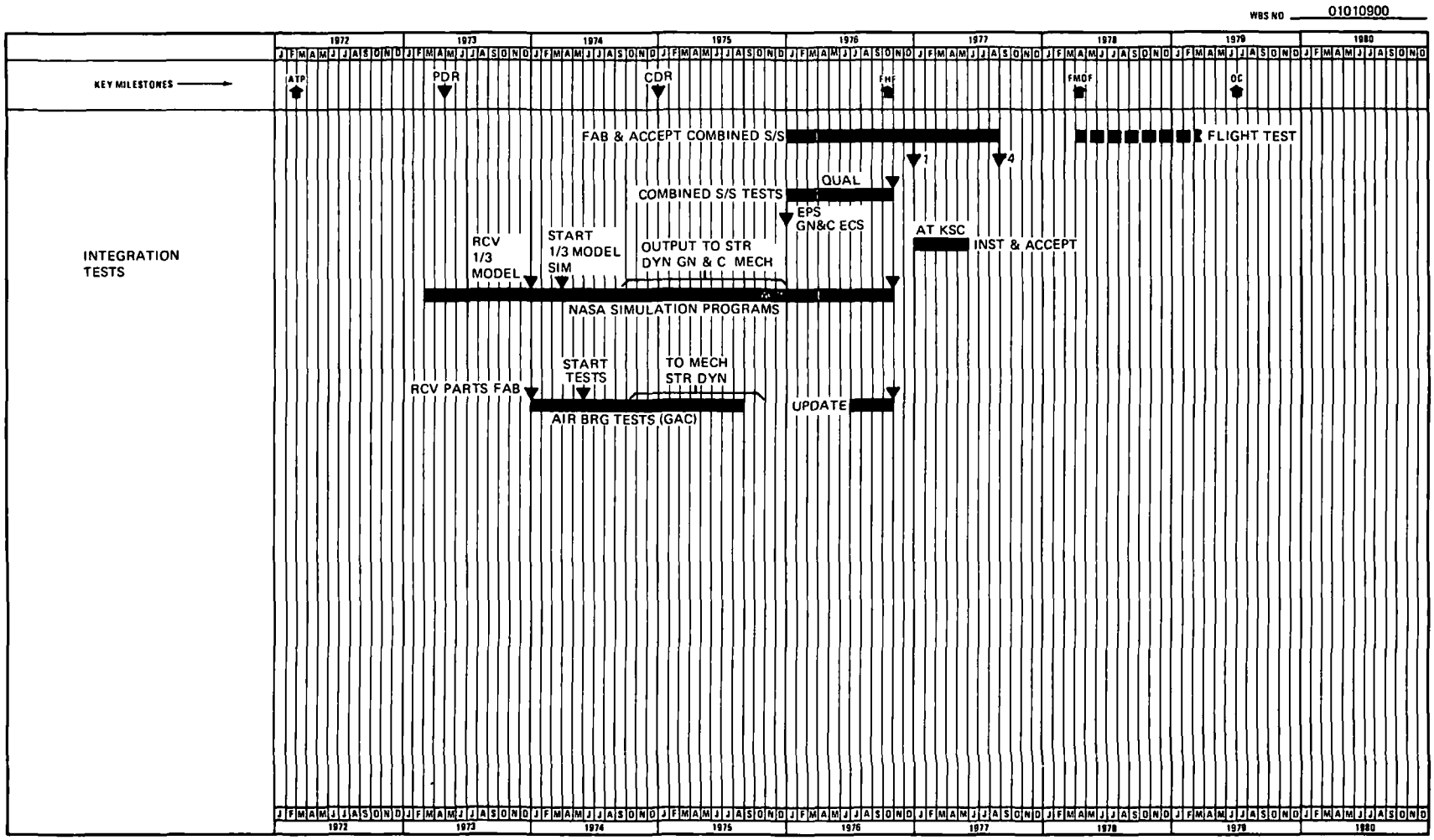

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Fig. 3.8-4 Payload Deployment Schedule (Sheet 2 of 3)

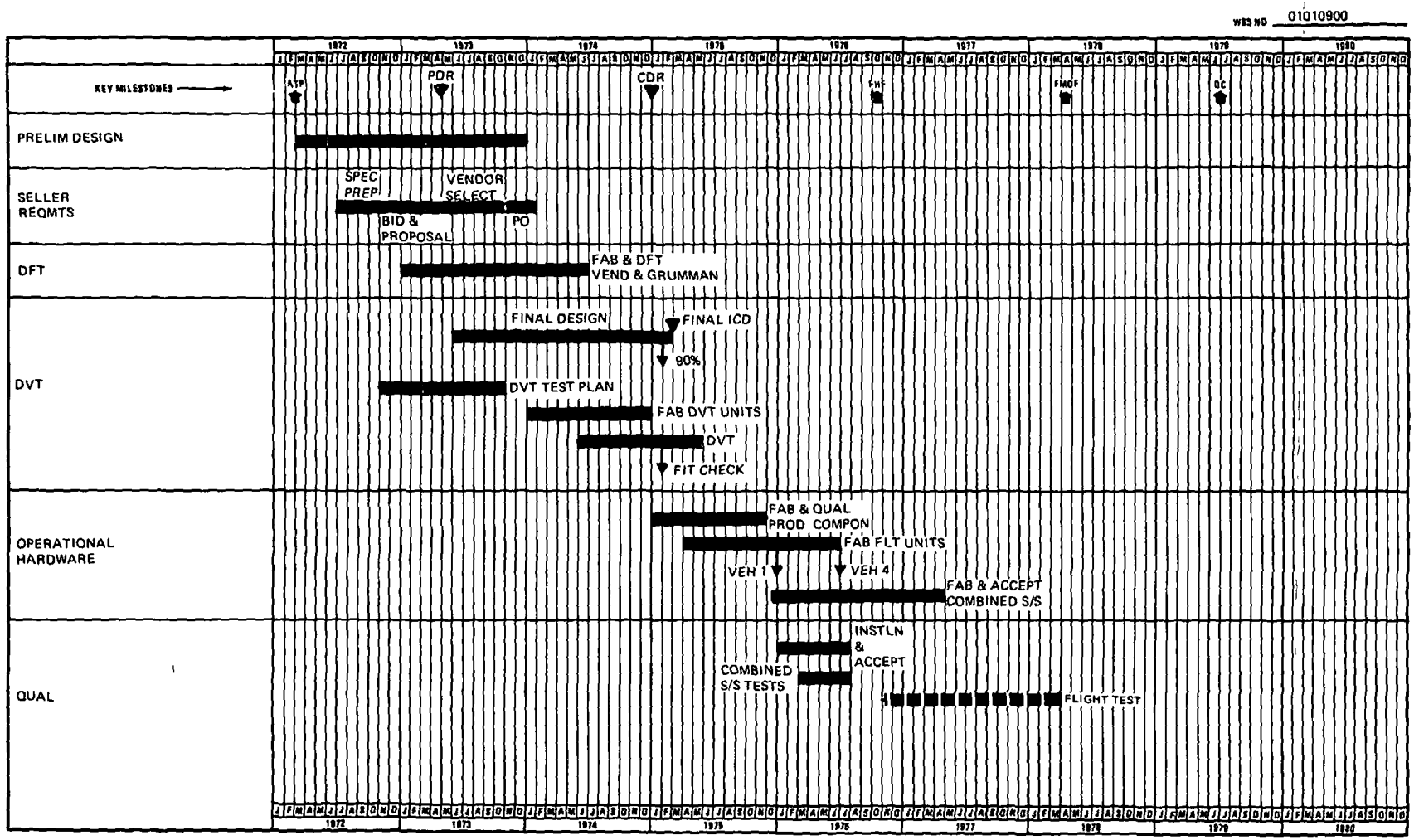

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Fig. 3.8-4 Payload Deployment Schedule (Payload Pallet) (Sheet 3 of 3)

TABLE 3.8-1 SUBSYSTEM CERTIFICATION REQUIREMENTS

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
Docking Mechanism											
Structural Adequacy					X	X	S		X		
Pressure Integrity (System)									X		
Flexible Tunnel						X	X				
Capture & Motion Attenuation	X	X			X					X	
Functional Performance (System)	X				X					X	
Latches, Hard & Soft						X		X			
Shock Attenuation	X	X				X				X	
Deployment					X						X
Electrical System					X						X
Sensor Alignment, Performance					X						X
Standard Interface Verification Mechanical, Fluid, Electrical Lighting, Avionics, Gaseous	X	X								X	X
Payload Pallet											
Structural Adequacy	X				X				X		
Standard Interface Verification Structural/Mechanical, ECS, EPS	X	X								X	
Shuttle Interface Verification	X				X						X
Auxiliary Equipment Interfaces	X	X								X	
	—	-		-							

TABLE 3.8-2 MAJOR COMPONENT LIST

Component Description	Qty/Vehicle	Weight Each, lb	Size Each	Power Each
Deployable Docking Mechanism	1	1500	50 ft^3	750W 30 sec
Deployment Actuators	2	125	6 ft x 1 ft dia	500 W 30 sec
Flexible Personnel Tunnel	1	300	60 ft^3	--
Aft Payload Support Assembly	1	30	1.5 ft^3	400 W 30 sec
Payload Support Pallet	1	1000	60 ft x 10 ft x 1 ft	TBD

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TABLE 3.8-3 REQUIRED EQUIVALENT UNITS

Hardware Description	Required Equiv. Units	
	Pallet	Docking
Flight Hardware Per Vehicle	1b	1
Component Devel & Qual Test	3	3
Integration Tests		
• Full Mission Simulation Laboratory		1/4
• Integrated Avionics Test Laboratory		
• Flight Controls Hydraulic Test Laboratory		
• Mechanical Systems Test Rigs	1	1c
• Propulsion Fluid Breadboards		
• Escape System Test Rig		
Test Articles		
• Propulsion Test Article		
• Structural Test Article	1	
Spares for Flight Test Program	1	1 1/4
Spares for 445 Flights	3	1 + 4a

a. 4 in bits & pieces - primarily seals & motors

b. Plus (TBD) in payload integration facilities

c. Plus 1/2 for mockup

TABLE 3.8-4 BOOSTER/ORBITER COMMONALITY LIST

Item	Common	Potential Common	Not Common	Remarks
Docking System			X	
Payload Pallet			X	

TABLE 3.8-5 SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

Item	Requirements
Support Equipment	Hydraulics stand for silicone fluids Environmental test stand for hot and cold tests (heater blankets and LH_2 + circulating fans) High speed cameras, oscilloscopes and recorders for latching tests Medium pressure (1500 psi) gaseous N_2 storage and transfer equipment Optical facility (or laser) Instrumentation consoles

TABLE 3.8-6 FACILITY REQUIREMENTS LIST

Title and Description	New	Exist.	Contr.	Govt.
High Bay Room for Air Brg. Tests, 150 x 150 Clear with Smooth Flat Floor		X		X
20-Degree-of-Freedom Docking Simulator		X		X
Thermal Vacuum Tank for 12 x 12 x 12 Ft Unit		X	X	
Explosion-proof Room to Check Pressure		X	X	
Structural Test Facility for Assembly Checkout		X	X	
Vacuum Tanks for Small Subassemblies		X	X	
Structural Test Facilities for Small Units		X	X	
Optical or Laser Test Facility for Docking Sensors	X			

3.9 PYROTECHNIC DEVICES SUBSYSTEM

Two major mission functions requiring pyrotechnic devices have been identified:

- External tank separation
- Escape seat sequencing and hatch(s) removal. This is limited to the first two aircraft

The development of systems to perform these functions will be based on design technology developed during the Apollo-LM and F-14A programs.

For the tank separation system, Grumman plans to use the modular concept for explosive devices and systems which is based upon a single, standardized electro-explosive initiator (NASA-MSC Single Bridgewire Apollo Standard Initiator, SBASI, P/N SEB 26100001). This initiator which has proven high reliability, will be the "first fire" unit in each explosive assembly. The modular concept enables control to be maintained over each subassembly in the pyrotechnic device. All lots of each subassembly are manufactured and acceptance tested separately and then finally in a complete pyrotechnic device assembly. The system will use triple redundancy (three functional modes) where feasible. The electrical portion of this system will have an isolated ground system, twisted shielded pairs of firing lines, etc. to give optimum protection against inadvertent firing.

The pyrotechnic devices portion of the escape system will be the percussion type using design techniques successfully demonstrated on the F-14A. The pyrotechnic devices will be used in seat sequencing and overhead hatch removal. The system, as a minimum, will have dual redundancy (two functional modes). Wherever feasible, explosive crossovers will enhance the redundancy.

The explosive compounds, deflagrating (pressure) and detonating (high order), will be selected on the basis of demonstrated reliability. For deflagrating compounds, Grumman will use metallic oxidant propellants consisting of suitable mixtures of zirconium and/or titanium hydride in combination with an oxidizer of potassium perchlorate. The products of combustion will be retained within the device after firing. For applications involving detonating compounds, HNS (hexanitrostilbene) will be used. The HNS will be confined in a fine grade silver sheath to withstand the effects of thermal cycling.

The facility requirements necessary to install pyrotechnic devices into the cockpit mockup are:

- Weapons Test Facility, Plant 6, Grumman, Calverton
- Ordnance Test Laboratory, Plant 2, Grumman, Bethpage

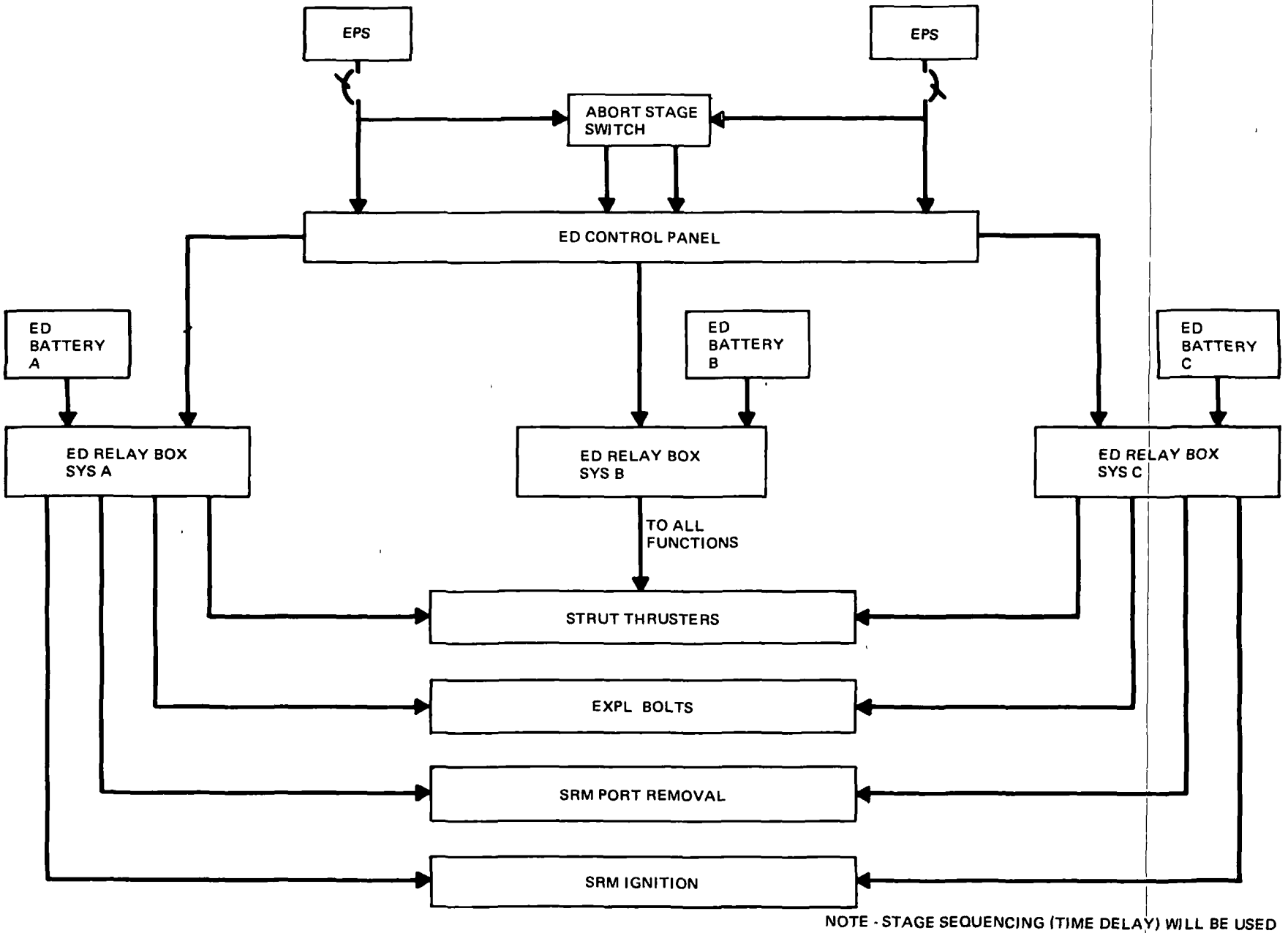

Fig. 3.9-1 Pyrotechnic Block Diagram External Tank Separation (2)

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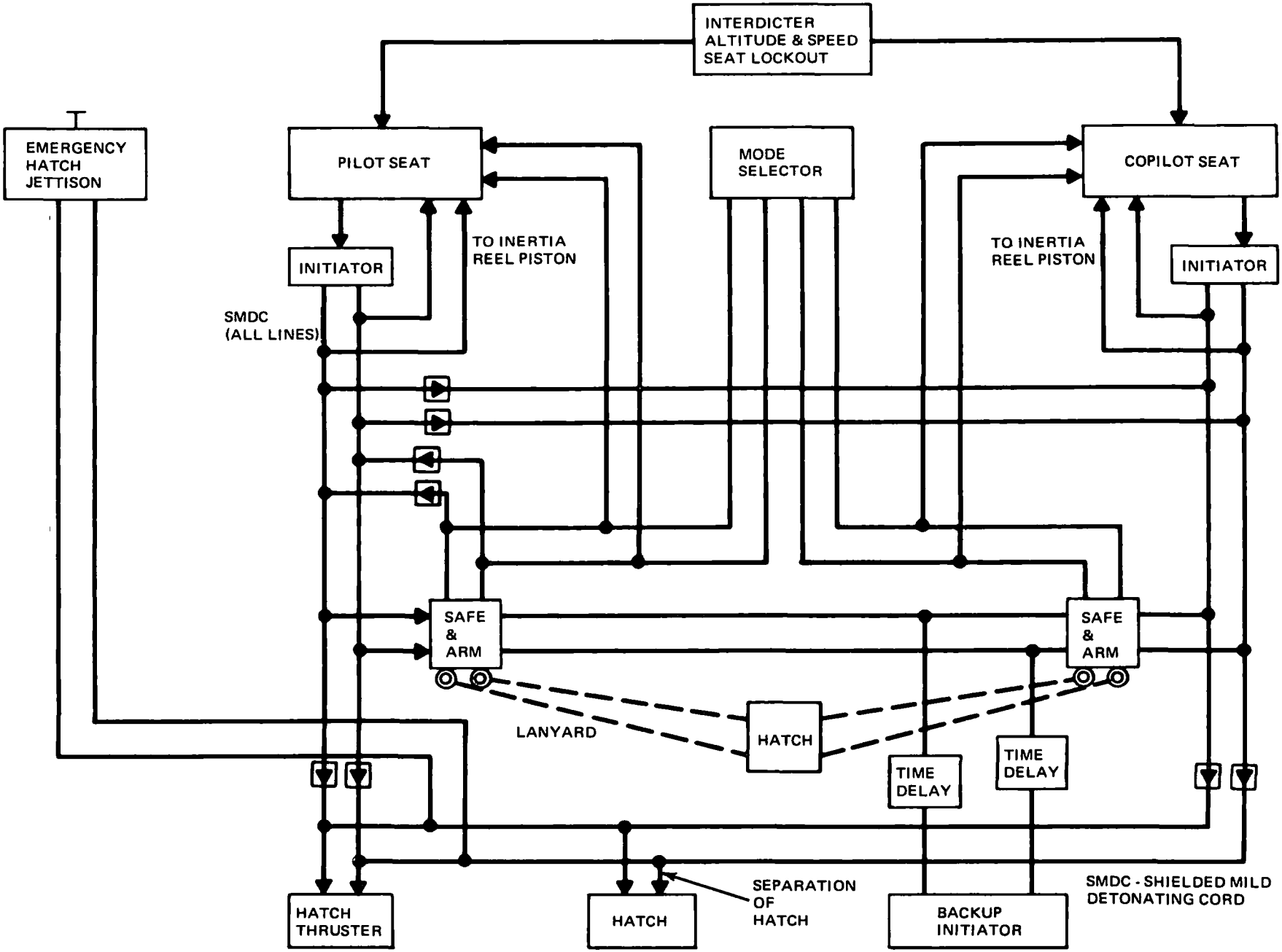

Fig. 3.9-2 Pyro Block Diagram Escape Seat Sequencing & Hatch Removal

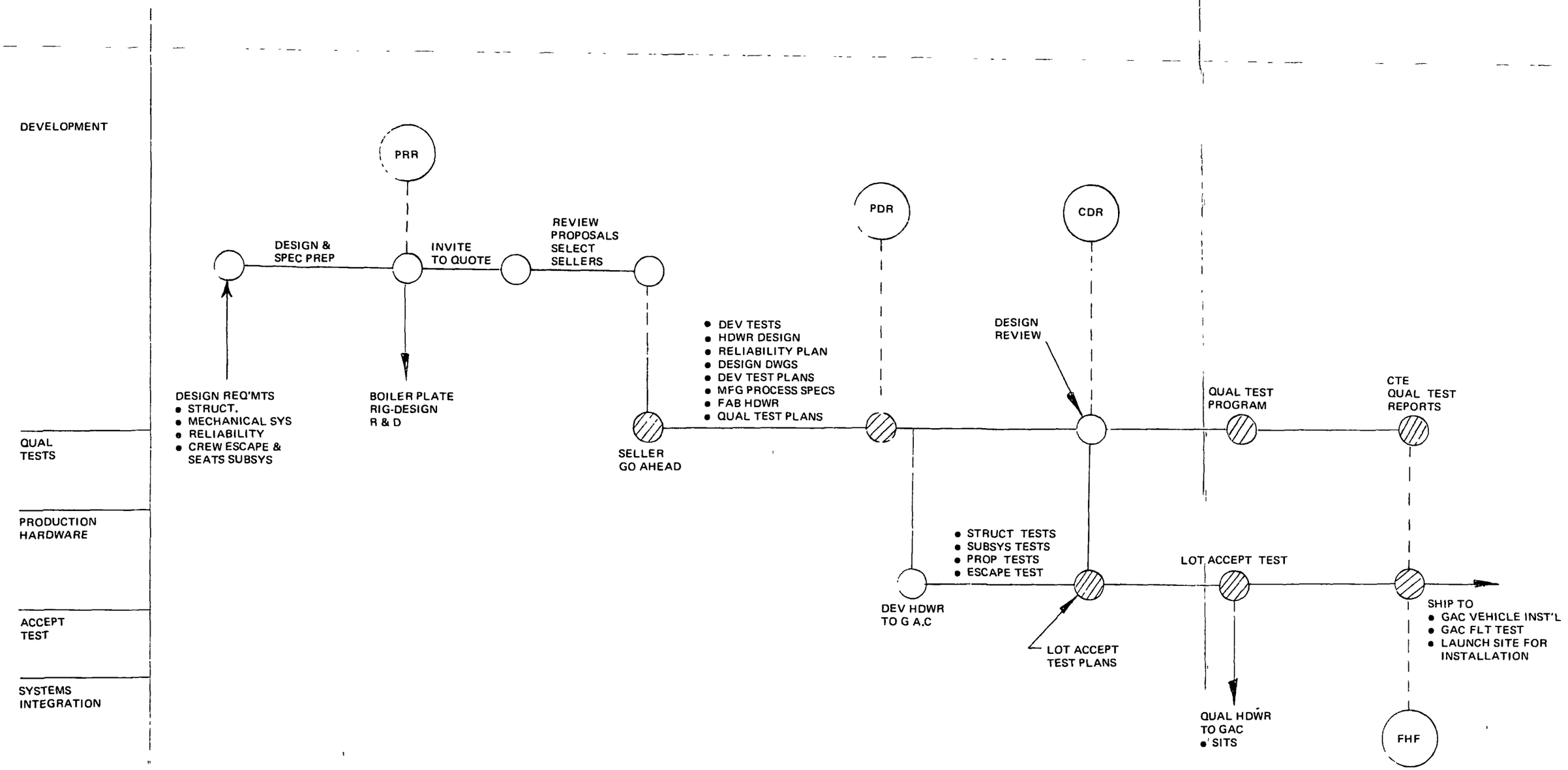

Fig. 3.9 Pyrotechnic Devices Logic Network

WBS NO 01010700

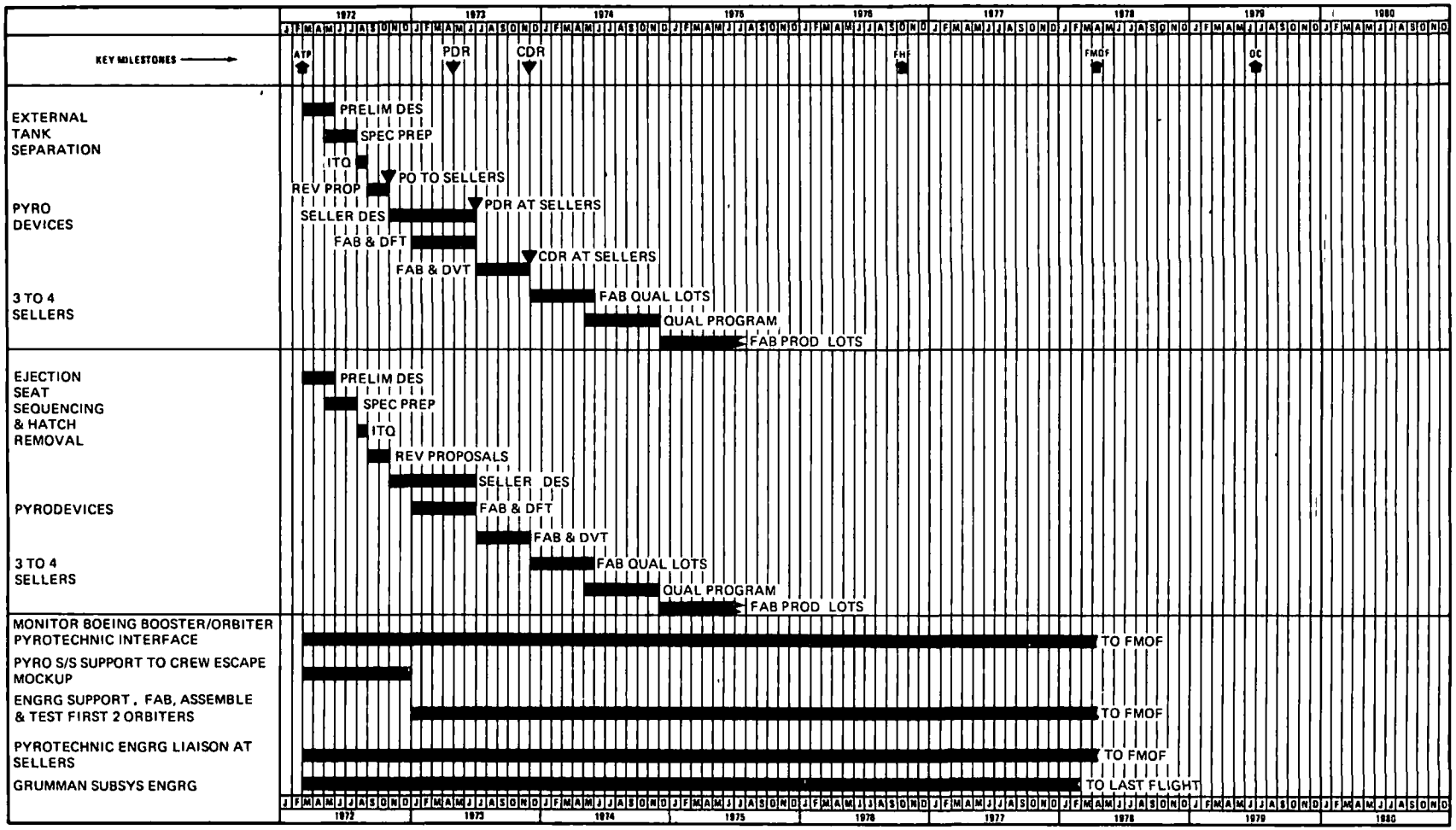

Fig. 3.9-4 Pyrotechnic Devices Schedule

TABLE 3.9-1 SUBSYSTEM CERTIFICATION REQUIREMENTS

Certification Requirement	Certification Method						Level of Assembly				
					Test						
	Analysis	Simulation	Similarity	Common Usage	DVT	Qual	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
External Tank Separation and Seat Sequencing and Hatch Removal											
For approximately 14 pyro devices:											
1) Verify functional capability of each component covering parameters such as:					X		X				
Minimum explosive load Flight explosive load Critical environments Max-Min flight loads											
2) Qualification - Expose each device to a complete environmental mission sequence. Verify that a portion of qual sample can function during flight environments and after ground environment						X	X				
Tank Separation & Seats Sequencing - Demonstrate that no anomolies exist in the above two systems re:					X	X				X	
Explosive residue in assemblies with multifunctions											
Sequencing											
Functional interactions											
NOTE: CTR tests above component level will be performed by mechanical systems (tank separation) and pyro systems SITS test (hatch separation and seat sequencing systems)											

TABLE 3.9-2. MAJOR COMPONENT LIST

Comp. No.	Component Description	Qty/Vehicle	Weight Each, lb	Size Each, cu. in.	Power Each,* watt, dc
	External Tank Separation				
1	Bolt, Explosive	18	1	9	--
2	Bolt, Cartridge	18	0.2	2	25
3	Thruster, Pyrotechnic	4	5	85	--
4	Thruster Cartridge	12	0.2	2	25
5	SRM Igniter Cartridge	4	0.2	2	25
6	Pin Puller, SRM Exhaust Port	2	1	6	--
7	Pin Puller Cartridge	4	0.2	2	25
8	Pyro Battery	6	3	54	--
9	Pyro Relay Box	6	8	400	--

* Does not include firing lines

TABLE 3.9-3. MAJOR COMPONENT LIST

Comp. No.	Component Description	Qty/Vehicle	Weight Each, lb	Size Each, cu. in.	Power
	Seat Sequencing & Hatch Removal				NOT APPLICABLE
1	Initiator	3	1/2	6	
2	Safe & Arm	2	2	20	
3	Hatch Thruster	1	3	144	
4	One Way Transfer	4	1/2	3	
5	Time Delay	3	1/4	4	
6	SMDC	300 lin ft	1/16 lb/lin ft	.4/lin ft	
7	Interdicter	1	3		
8	Mode Selector	1	2		

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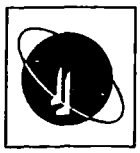
TABLE 3.9-4. REQUIRED EQUIVALENT UNITS

Hardware Description	Required Equiv. Units	
Flight Hardware Per Vehicle	1	1
Component Devel & Qual Test	10	10
Integration Tests		
• Full Mission Simulation Lab		
• Integrated Avionics Test Lab		
• Flight Controls Hydraulic Test Lab		
• Mechanical Systems Test Rigs	5	5
• Propulsion Fluid Breadboards		
• Escape System Test Rig		
Test Articles		
• Propulsion Test Article		
• Structural Test Article		
Spares for Flight Test Program	20	1
Spares for 445 Flights	445	2
	Tank Separation	Escape Seat

TABLE 3.9-5. BOOSTER/ORBITER COMMONALITY STUDY

Item	Common	Potential Common	Not Common	Remarks
Design Philosophy				
Orbiter Tank Separation vs Booster/Orbiter Separation			X	
Escape Seat Sequencing & Hatch Removal		X		
Equipment				
Escape Seat Sequencing & Hatch Removal		X		

TABLE 3.9-6. SUBSYSTEM SUPPORT EQUIPMENT/SOFTWARE REQUIREMENTS

Item	Requirements
Support Equipment	1. ALINCO bridgewire resistance tester 2. Insulation resistance (Megger) 3. Simulator initiator 4. Firing console
Software	None

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